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THE SCIENTIFIC MONTHLY

MARCH, 1920

SPACE, TIME, AND GRAVITATION[1]

By Professor EDWIN B. WILSON

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1. *Unrest in Physical Science.*—What you ask me to perform in presenting to you some discussion of the new conception of the categories of space and time suggested by Einstein's treatment of universal gravitation is a task that I accept reluctantly, even among friends and philosophers, because the matter is so new that an adequate judgment can no more be given to-day than a satisfactory judgment upon Maxwell's theory, whether in its philosophical or its physical significances, could have been given in the early days when he was forming it in his memoirs and before the appearance of his great treatise.

There is moreover, to-day, in the physical world a general unrest, little realized by non-physicists, and quite unlike the condition, I believe, existing fifty years ago. This unrest leads physicists to alternate, according to their temper, between a despair of ever settling the physical bases of the many new facts which experiment is thrusting upon them and a desperate grasping at any theoretical straw that offers even a feeble chance of support in the flood. In this generally febrile condition of our science it is particularly unsafe to draw philosophical conclusions.

When I read books or essays on philosophy that which impresses me most, next to their appearance of getting nowhere, is their apparent attempt to get universal judgments. I realize that much of this impression is probably due to a misconception on my part of the technical terms employed by philosophers. Such words and phrases as "Absolute," "original," "ultimate

[1] Read before the Royce Club, Boston, January 18, 1920. The first address to the Club, by its Founder, Professor Josiah Royce, appeared in *Science*, 39, April 17, 1914, pp. 551–566.

ground," "the eternal and immutable," "final causes," "first causes" and "comprehensive view of the universe as a whole" are quite unintelligible to me, although the last which contains "comprehensive," "universe," and "as a whole" seems on its face to be so far emphatic of something that I might reasonably expect to have a precise idea of what that something may be. To me this sort of phrase represents merely emotional aspiration.[2]

I say this in no spirit of contumely; for I shall probably use to-night many technical terms of but poor intelligibility to others—try as I shall to avoid them—and, besides, I suppose that next to the philosopher nobody so insistently tries to reach the "ultimate" as the theoretical physicist!

2. *The Dynamical View of Nature.*—I have spoken of the scientific unrest. The world seems to run in waves of excitement and of hum-drum, of discovery and of codification.

Two hundred years ago Newton set up the fundamental laws of kinetics and of gravitation. Little by little the major part of accurately known Nature came under the régime of these laws. A hundred years ago Laplace had shown the marvelous accuracy with which astronomical observations could be accounted for, and when Ampère and other continental workers came to develop the theory of electric and magnetic phenomena they followed the astronomical model. Stokes and Kelvin were students of dynamics and exponents of the dynamical explanation of Nature.

There was a time some fifty years ago when there was in the minds of many a belief that a dynamical account of the world at large was clearly foreshadowed. Maxwell, to be sure, gave up action at a distance; but, trained as he was in the English school, his point of view was largely dynamical—the dynamics of media, of the special medium known as the ether. He tried, and Kelvin long continued to try, to construct a mechanical model of the ether. There were bizarre theories of matter on a hydrodynamical basis—the atom founded on the persistence of vortices in perfect fluids, the atom built upon the theory of sinks and sources, and finally, not so long since, the general structure raised by Reynolds on the basis of a granular ether.

So happily did phenomena fit into the dynamical theory of

[2] May it be that some philosophers mistake emphasis for precision and description for definition? In times past mathematicians have used terms like "infinite," "infinity," "infinitesimal," "sum of a series," "differential," "imaginary," without sufficient precision in definition with resulting inconclusiveness of proof, fallibility of analysis, and bitter polemic even though confining themselves to much simpler questions than philosophers treat.

Maxwell and so near were we to a satisfactory material basis for the all-pervading medium that not a few of our ablest physicists two or three decades ago felt that we had already entered the hum-drum period of physics where the chief contributions were bound to be merely the more careful determination of physical constants—we were entering upon the reign of the "next significant figure." That there was need for this emphasis on accurate measurement will be granted by all who realize the pitifully inaccurate condition of electrical measurements, the large degree of indetermination in our standard electrical units, which then existed.

3. *The Flood of New Phenomena.*—As a prediction, however, of the future of physical science, the hum-drum forecast was bad. Perhaps the naturalist is too wise to hazard a guess that the future of his science is largely routine. But the outlook of some physicists in the middle nineties was not unlike that of the classifying naturalist who should hold that the thing best worth while was to get some money and some quinine and go in search of a new gnat in South America or a novel Nymphæa in Africa—quite blissfully ignorant of the great new realms of biology that would be opened by Mendel.

In the last twenty-five years we have learned that the atom is not indivisible, but consists of small charged particles or electrons. The physicist likes to have these particles in circular motion; the chemist wants them at rest except for oscillations about a position of equilibrium. We have learned about X-rays —some things about them—and through them we are learning much about many things. We have learned of radioactivity and the self-transmutation of certain elements. We have learned that radiant energy, at least in some of its manifestations, seems to possess a discrete or discontinuous structure, this leading to the perplexities of the quantum theory—perplexities not of physics alone but of mathematics and probability as well. Here is cause enough for unrest.

It may be that to give a satisfactory treatment of quanta we shall have recourse to a belief that space or time or both are themselves discontinuous and that their seeming continuity is but a statistical affair like the continuity of a fluid or solid. There is apparently a long-period oscillation in physics between the continuous and the discontinuous, and there is no reason why in some of its excursions the pendulum should not reach space and time.

4. *The Results of Careful Experiment.*—It is not only the great new things we have learned that trouble us; refinement of

measurement is itself a two-edged sword. Our physical laws are designed to correlate our observations. The correlation may remain good while our measurements are good only to three significant figures and become impossibly bad when we can determine five or six figures.

It has been known for some time that the perihelion of Mercury advances 42″ per century, and Newton's law of gravitation has given no wholly satisfactory account of this advance; there are also some slight unexpected secular variations in the moon's motion—enough perhaps to be visible to the naked eye after some thousand years. So either Newton's law is not perfect or there must be unknown masses, of relatively small amount, circulating in the solar system.

Turning to another branch of physics we have the exceedingly accurate experiment of Michelson and Morley wherein a ray of light is split, part being sent along the direction of the earth's motion to one mirror and back, part being sent an equal distance along the perpendicular direction and back. Now if the light travels in the ether with a velocity dependent only upon the elastic or quasi-elastic properties of the ether, the light going in the direction of the earth's motion and back will, owing to the motion of the mirror, travel a trifle farther than that going in the perpendicular direction. The difference in path amounts under favorable circumstances to about one half of one millionth of one per cent. of the path. This is not much, to be sure, but it should show very plainly in such accurate work as is done in interferometry, and it does not show.

One possible explanation would be that the earth drags the ether with it just as it drags its atmosphere; but there arise serious difficulties when this suggestion is pursued. Another explanation might be that there is a shortening of matter in the direction of motion—and this has been followed up by Lorentz.

5. *The Electric Theory of Matter.*—The suggestion of shortening is not unnatural on the electromagnetic view of matter. When a charged sphere moves, the lines of force, instead of remaining isotropically divergent from the sphere, crowd up toward the equatorial plane perpendicular to the direction of motion and leave the poles of the sphere in the direction of motion with a smaller superficial charge. The tendency of the sphere is to shorten in the direction of motion. Now if all matter is made up of electrons, and if the electrons themselves tend to shorten in the direction of motion, with the attendant alterations in their field of force, it is not unreasonable to sup-

pose that all matter suffers the same shortening when moving through the ether.

The shortening is greater as the velocity of motion is greater. For the earth which moves only 30 km. per sec. in its orbit about the sun, the shortening is only a few inches in 8,000 miles. For an electron which may move at 9 tenths the velocity of light, the shortening is more than half, and if an electron should move at 99 hundredths of the velocity of light, its diameter in the direction of motion would, on this hypothesis, be only one seventh its original amount so that the electron would appear disc-like instead of spherical.

There is another effect of the shortening which is calculable, and that is the gain in electrical energy, and the gain in inertia. A flattened electron when accelerated in the line of its motion tends to become flatter; part of the work done by the applied force must go into crowding the lines of force toward the equatorial plane and hence only part remains over to accelerate the mass. The result is that for a given force the acceleration is less than if the flattening did not take place, or to put it differently, the mass or inertia appears greater. Thus the electron has conceivably two masses or inertias: one due to its mechanical mass, the other to its electrical inertia, and the latter part varies with the velocity in a perfectly definite way. When the experiment of determining the inertia of the moving electron is tried, it is found that apparently all the inertia is that of electrical origin with none left over for ordinary mechanical inertia.

This discovery suggested very strongly that the day for a mechanical explanation of nature has definitely passed and that henceforth, at least for the immediate future, the attempt should be made to give an electrical foundation to mechanics and to all natural phenomena.[3] J. J. Thomson, as a matter of fact, long previously had shown theoretically that a charged material sphere has additional inertia by virtue of its charge, but for ordinary spheres the amount of added electrical inertia is inconsiderable compared with the mass of the material. It was only when the infinitesimal and relatively enormously charged electron became available for direct experimental work that the

[3] The attempt to give a unitary basis to the whole of physical theory has an irresistible fascination and physical theory advances by the strife between this monadic ideal and the ever-growing volume of physical fact. It is like the contest between armor plate and the armor-piercing projectile. Sometimes one appears to be winning, sometimes the other; on the whole, it is a draw. What we have at any time is not one physical theory, but a congeries of theories. See a note by G. W. Stewart, *Science*, 51, 1920, pp. 95–86.

amount of the electrical inertia and the law of its increase with velocity could be determined.

6. *The Old Relativity.*—This idea of shortening in the direction of motion was physically satisfying, but not so philosophically. Space and time are not absolute. Every point of space is just like every other and the only position known or knowable on the basis of Euclidean geometry is relative position. There has been since Newton's time, and before, a natural belief in a principle of relativity. Neither absolute position nor absolute uniform velocity are determinable.

The laws of motion, when resolved far enough, show this. We have to do with accelerations of particles and the value of the acceleration of a point is unchanged when the position of the point is specified by reference to any set of axes whether at rest or moving uniformly parallel to themselves. (The acceleration is affected by a rotation of the axes.) Moreover, the acceleration is not altered by any choice of an initial instant from which to measure time. Finally, as the action and reaction between two particles lie in the line joining them and are supposed to depend only on the distance between the particles, the forces which enter into the equations are expressed in terms of quantities (*i. e.*, distances) which are independent of the choice of axes. Thus arises a belief in relativity.

It is true that the equations of motion for definite bodies moving under the definite conditions inherent in some particular problem may not be analyzed down far enough to reach the simple invariant form indicated. For example, a resistance may be taken as a function of a velocity—a statistical form of expression which gives the gross resultant action of all the myriads of air particles on a bullet. Yet we should believe that if each gaseous molecule were considered, the forces would be representable as functions of the distance; and indeed even when we insert a velocity into the equations of motion it is always regarded as a relative velocity.

We have then in ordinary mechanics a full-fledged, if sometimes quietly ignored, principle of relativity. All that can be treated or known is relative motion when translation is concerned. Newton noticed the difference arising in the case of rotation, which of course involves acceleration even when the angular velocity is uniform.

7. *The Absolute Ether.*—Return now to the ether. This is regarded as a medium filling all space and fixed except for its tremors which show us light. The ether furnishes an absolute

material space, so to speak—and motion becomes conceptually motion relative to the ether. But as no effect of motion of the ether itself (except its tremors about its mean position) has been detected, there is no reason why the ether in its mean position should not be regarded as an absolute and motion relative to it as absolute motion. If this be so, those who desire "absolutes" have their innings.

Here is where the famous Michelson-Morley experiment comes in. If the ether is at rest, pervading all matter but not dragged with it, an interference experiment should clearly show the drift of the earth through the ether—not only the drift due to the motion about the sun, but the drift to the motion of the solar system towards its apex. And the result of the experiment was negative. So also were the results of other experiments which by other means should detect the drift. These negative results may all be explained by shrinkage in the line of motion.

Why then should this effective physical explanation be philosophically unsatisfying? Because. Just because. This is "a woman's reason." It is a good one. I know of none more convincing. Perhaps part of the dissatisfaction is due to our long-continued belief in relativity fortified by a growing distrust of any absolute background which refuses in any way to disclose itself as in motion relative to us.

If lengths in the direction of motion shorten, our measuring instruments shorten so as exactly to counterbalance the abbreviation of the thing measured. Why then should we believe in the shortening at all? May it not be that the shortening itself is only relative? That is, if A and B, being in relative motion, observe a distance PQ with meter sticks which are identical when at rest, A and B will differ on the measure of PQ by perhaps one half of one millionth of one per cent.; but why should B claim that it is A who is in motion and who has not corrected for his shortening—why may not A equally well claim that it is B who is in motion and has not corrected for his shortening? And if a third party comes in as referee, and makes a finding different from both because neither is at rest relative to him, what then?

8. *The New Relativity, Space and Time.*—This sort of question did not bother many until Einstein raised it and started out to solve it by boldly affirming that we must construct our space and time concepts in such a way as to avoid these discrepancies and give us a real relativity consonant with physical fact and

independent of the opinions of different observers as to who is and who is not in motion.

A fundamental postulate of his theory is that the velocity of light $c = 3 \times 10^{10}$ cm./sec. appears the same to all observers. This means that velocities do not add according to the ordinary law. Any velocity compounded with the velocity of light gives the velocity of light—no more, no less. Two velocities in the same direction do not compound into the sum of those velocities but into that sum diminished by a small amount.[4] The geometry of velocities, so to speak, is non-Euclidean.

A still more striking revision of ideas is necessary relative to space and time, because these two conceptions become necessarily interrelated, whereas in Newtonian relativity they were independent. Two observers with relative motion measure space differently; they measure time differently; they do not even have the same space and the same time, because the time *or* space measure of either depends on the space *and* time measure of the other, in such a way that they do not agree even as to the simultaneity or not of events happening at different positions—nor do they agree as to the identity or non-identity in position of two events happening at different times.

A fusion of the time and space concepts into a single time-and-space idea is necessary to bring simplicity out of the confusion. What this does to the metaphysician who is interested in settling "what it is that we know and how it is that we know it" is more than I can say. Such discussions as I have read of the categories of space and time would seem to have very little left as an ultimate residuum.

9. *Knowledge of Nature.*—In an article on metaphysics[5] by a philosopher with obvious sympathetic leanings toward Aristotelian methods and an Aristotelian realism I find this qualification in summary: "Aristotle could not know enough, physically, about Nature to understand its matter, or its motions, or its forces; and consequently he fell into the error of supposing, etc." Now relatively speaking there is a good chance that Aristotle in his day did know more, physically, about Nature than a philosopher of to-day can know. There was much less known about Nature then and the sort of thing known was much simpler, and Aristotle was a profound student of Nature with

[4] If B's velocity appears to A as u and C's velocity appears to B as v, then the composition of the velocities is by definition that velocity which C appears to have to A. In ordinary mechanics this is $u + v$, in relativist mechanics it is not.

[5] See "Metaphysics," Encyc. Brit., 11th ed., Vol. XVIII.

the best resources of his time largely at his disposal. Aristotle probably knew Nature better than a physicist to-day knows physics or a chemist chemistry.

Here again I must state that I am not trying to be contumacious toward the philosophers in this group. I appreciate thoroughly that our Founder tried to collect into this aggregation students of many a field for the very purpose of pooling our philosophical interests and our scientific information of mutual philosophic import. I wish to emphasize merely this: That nobody at any time can know enough about Nature to understand its matter, or its motions, or its forces and that consequently everybody will fall into error if he goes to supposing this or that or anything else which is of the sort that later discoveries may upset.

Certainly it is difficult to ascertain what it is that can not by any future development be upset—and as I understand them this it is, and this alone, that interests many philosophers. With Einstein's relativity of 1905 space and time as separate things disappeared into the space-time fusion. Does everybody believe this? By no means. The great majority are still either indifferent to it, because it does not immediately affect their work, or set against it because it is not "physical" but "philosophical."

10. *Force, Real or Fictitious.*—Query: When is a force not a force? Answer: When it is a "reversed effective force." To amplify this conundrum I will recall to your mind the general principle of d'Alembert to the effect that: The impressed forces acting on a body taken with the reversed effective forces form a system in equilibrium. This amounts really to transposing the terms in the equation $Ma = F$ so that $0 = F - Ma$. The force F is the impressed force, the force $-Ma$, the negative of the mass times the acceleration, is by definition the reversed effective force.

This principle is of great convenience. It enables the engineer to treat a problem of motion in a curve by the introduction of the fictitious "centrifugal force," which is of course the reversed effective force—not a true physical force (the physical force is centripetal). By this fiction the force-analysis relative to the body in curvilinear motion is reduced to a simple static diagram.

Suppose we are in a uniformly moving train and cannot look out. Thanks to the principle of relativity, all goes nicely according to the Newtonian laws, until we strike a curve. Then everything has an outward acceleration—apparently. Really there is

no outward acceleration. The bodies are merely trying to maintain themselves in uniform motion in a straight line—at least this is the interpretation we have come to put on the phenomenon since Newton's time.

Now as a matter of fact we are on a very smoothly running train all our life; but the earth turns with so small an angular velocity that it has been only in recent times that it has become convenient, and consequently real, among scientists, to regard the world as turning. And only in still more recent times have refined experiments such as those with Foucault's pendulum and with gyrostats shown us before our very eyes this rotation of our frame of reference. We may regard the earth as non-rotating if we choose, but the introduction of "centrifugal" and "Coriolis" forces which are fictitious reversed effective forces. Indeed, for the solution of such problems the introduction of these fictitious forces is generally more convenient than to use a fixed frame of reference, even though we know better than to adopt as a philosophy a non-rotating earth and as physically existing the fictitious forces in question. We are very wise about things we have long since come to believe.

But just suppose that somebody tells us that the force of gravity is physically non-existing quite as much as the centrifugal or Coriolis force, and that the reason we think that gravity is real is essentially the same that leads the untutored mind to believe there is a physical force acting to move objects to one side when a train goes around a curve—namely, an unhappily ignorant view of Nature. This is what Einstein asserts.

11. *The Space-Time Path.*—He goes further and maintains that instead of every particle of matter attracting every other particle according to the Newtonian law, each particle goes its way on the shortest or straightest path possible, when both time and space are considered in a single space-time manifold.

That the path of the planets is really nearly straight may easily be seen. In the motion about the sun the earth turns through about 1 degree per day and departs from its rectilinear motion by 22,000 kilometers in 2,600,000 when space alone is considered. But, using the velocity of light as a standard, 1 second of time is equal to 300,000 kilometers of distance. Hence in a day, which is 86,400 seconds, the advance in time is the equivalent of some 26 billion kilometers, while the motion in the path is only one ten thousandth as much and the motion across the path is only 22,000 kilometers or less than one millionth as much.

In the space path we have a departure per day from rectilinear motion of about one part in a hundred; on the space-time path the departure from rectilinear motion (motion with uniform velocity) is about one part in a million, which represents a much smaller curvature—the path is nearly straight.

This may all be made clearer by regarding the space-time path as constructed in the following manner. Draw from the sun perpendicular to the plane of the earth's orbit a line which shall represent the time-axis and disregard the third spatial dimension. Now for each km. that the earth moves around in its orbit, it must be considered to move in time by 10,000 km. The path of the earth in space and time on this diagram is therefore a helix with an extremely steep pitch winding once per year about the cylinder standing in the earth's orbit but advancing ten thousand billion km. while "circulating" one billion km.

Such a helix departs very little from a generator (vertical element) of the cylinder and is nearly straight. Not much quantitative change in our space-time measurements, however great the qualitative change might be in our space-time concept, might make the space-time path a geodesic or shortest path in a curve space-time manifold. Einstein shows how to make the change.

The mathematics is complicated; it depends on the theory of quadratic differential forms which to me seems perhaps the most intricate branch of pure mathematics and is at all events one unfortunately little studied in America—or anywhere else except in Italy. Einstein himself stumbled many times before he succeeded, not without the aid of others, in making the change he desired, but his progress toward his objective was relentless and must have required both a keen imagination and an iron will.

12. *"Curved" Space.*—A word about curved space. This is a difficult concept to non-mathematicians. All will admit that a two-dimensional spherical surface is curved in three dimensions. The difficulty is in seeing how a person limited to two dimensions in his motions and without any imagination of a third dimension could conclude from his observations on the spherical surface that the surface was not flat but curved. Or how we, limited to three dimensions, could by observations in three dimensions decide that our space was curved. Or, still worse, how we, limited to four dimensions of space and time, could by observation determine that our space-time manifold was curved.

Let us consider the case of the spherical surface and compare it with that of the plane. Suppose the plane inhabitant selects an origin O and a line OL issuing from it and specifies the portion of a point P by the distance OP of P from O and the angle POL giving the "bearing" of P relative to OL (polar coordinates). Then he will find that the distance between two nearby radial lines OP and OP' at equal distances $OP = s$ from the origin O will be the product of $OP = s$ and the infinitesimal angle POP', and that the length of the circle about O as center and with OP as radius is $2\pi OP = 2\pi s$.

Now the inhabitant of the sphere will find a very different result by the similar procedure. He selects his origin O and line of zero "bearing" OL. (This line will from our external point of view be a great circle, but from his point of view a straight line or geodesic, because its curvature being wholly normal to his space is not directly perceptible.) He will find the infinitesimal distance at any point between two nearby lines OP and OP' not as OP times the angle POP' but as this product multiplied by $\sin s/a \div s/a$ and the whole periphery of the circle equidistant from O not as $2\pi OP$ but as $2\pi OP$ multiplied by the same factor, where a is some constant.

The difference between the results

$$2\pi s \quad \text{and} \quad 2\pi s \times (\sin s/a \div s/a)$$

for the perimeter of circles of radius $OP = s$ is surely significant of something. You may call it significant of the curvature of the sphere even though you attach no other significance to the word curvature. It is indeed probable that the use of the word curvature here is attributable to our three-dimensional view of the sphere.

When we work in our flat three dimensions we find the area of a spherical surface of radius OP to be $4\pi\overline{OP}^2$; if we should find it to be something else such as $4\pi\overline{OP}^2 \times (\sin s/a \div s/a)^2$ we should attribute this to some property of our space and seek to interpret the constant a relative to the space. We may or may not speak of our space as curved but we do at least recognize that the formula for the area of a sphere of radius OP is not directly proportional to the square of OP when OP is large though it is when OP is infinitesimal relative to the constant a.

In the Newtonian relativity space was flat and independent of time; in the Einstein relativity of 1905 space and time had to be considered together but the manifold thus obtained was still flat and no special account was taken of gravitation, the theory was essentially electromagnetic in the sense that it was fitted to

the electrical conception of Nature; in the Einstein new relativity space and time must still be considered together but the space-time manifold has become curved and the curvature has been so adjusted that the major effects of gravitation, as ordinarily considered, have been accounted for by the curvature of the space-time manifold so that every particle of matter pursues a geodesic or straightest path in the four-dimensional manifold.

The further explanation of detail is complicated by the fact that there are different sorts of curvature. Consider again the spherical surface. There is one curvature, called the mean curvature, which is estimated relative to the radius and is exactly equal to the reciprocal of the radius, $1/a$. There is another curvature, called the total curvature, which is estimated relative to the square of the radius or to the area and is taken as equal to the reciprocal of the square of the radius, $1/a^2$. On the sphere both curvatures are constant; in the plane both are zero. On a cylindrical surface of radius a, the mean curvature is $1/2a$, the total curvature is zero, both are constant.

An interesting class of surfaces is that formed by soap films stretched across various forms of wire. The film has to stick to the peripheral wire, but is otherwise free to contract under the influence of the surface tension of the film. The result is that the film shrinks into the form of the surface of least area, the so-called minimal surface, which can span the periphery. Such surfaces have their mean curvature constantly equal to zero. They are saddle shaped with as much positive curvature in one normal section as there is negative curvature in the perpendicular section; the total curvature of such surfaces is negative and variable, being zero at the periphery where the film is attached to a segment of straight wire. In stepping up to three dimensions there are curvatures expressible as reciprocals of lengths, or of areas, or of volumes, and of these the first two are types of mean curvature, the last of total curvature.

Generalizations to four dimensions may be made. But when we have to deal with gravitational effects of matter considered to be at rest, as is the case with the dynamics of the solar system so far as these are attributable to a sun regarded as at rest (and in abstraction from all perturbative effects) it has been shown by Levi-Civita that space and time may be separated (as is also the case in the 1905 relativity where observers agree as to what is at rest) so that phenomena pass in time and in space.

The three-dimensional space surrounding the central sun is, however, curved, but with zero mean curvature much as the

soap film is curved but with no mean curvature. Within the mass of the sun the mean curvature is not zero, but is intimately connected with the density of matter or of energy.[6] For Einstein's theory is one of energetics.

13. *Energy and Mass.*—We have stated the theory chiefly with relation to its modification of our space and time concepts and with but little account of its underlying physics or philosophy except in so far as concerns the early relativity of 1905. It is necessary to return to the physics and philosophy of Einstein between 1905 and 1915.

It was seen that the mass or inertia of any electron was wholly electrical. Now mass according to our older concepts has two properties—inertia and weight, for both of which Newton set up the quantitative formulation. Does the electron weigh? Is the electrical inertia, which is proportional to the electrical energy, of the electron subject to the law of gravitation? If matter is wholly electrical, the simplest hypothesis is that the electron does weigh.

A beam of light represents energy; according to Maxwell it represents also momentum which should be disclosed as the pressure of light when the light is either absorbed or reflected. The pressure has been measured. Light, therefore, has the two principal characteristics of moving matter, energy and momentum, why should it not have the other two, inertia and gravitation?

The physicist generalizes on very slight evidence if his fancy, his esthetic sense, is sufficiently insistent. We have come to believe[7] that every quantity of energy, of whatever sort, represents just so much mass, that every amount of mass represents just so much energy of some sort, and that every bit of energy attracts every other bit of energy just as much as every particle of matter attracts every other particle—which on the new theory is really not at all, so that we must state it other-

[6] That Einstein's gravitational theory makes it *necessary* for us to think of our space-time manifold as curved I would not say. The non-Euclidean plane geometry of Lobatchevsky may be developed without specific reference to the curvature of the Lobatchevskian plane; or it may be treated as the geometry on a surface of constant negative total curvature such as the pseudosphere; or, by the aid of the Cayleyan system of measurement, as a type of geometry inside an ellipse or circle in the Euclidean flat plane. See "Geometry," Encyc. Brit., 11th ed., Vol. XI.

[7] I am here trying merely to state Einstein's ideas as I understand them, as throughout this paper, without wishing to give the impression that all of these ideas are yet universally accepted or even certain to become widely accepted. The theory is still young and may succumb to infant diseases instead of to general disintegration after a ripe old age.

wise, namely, that every particle of energy puts its appropriate crimp into our space-time manifold. Or to give a better phrasing, departures of our space-time manifold from flatness are correlated definitely with what we otherwise term energy.

The numerical relation between mass in grams and energy in ergs is this: The mass is the energy divided by the square of the velocity of light. Thus one gram of matter represents 9×10^{20} ergs or over 21 billion calories. Conversely, a hot brick is heavier than a cold one—it has more mass by the amount of heat added if measured in ergs and divided by 9×10^{20}. To heat 1 kg. of water 100° C. requires about 4.2×10^{12} ergs; the increase in mass or weight is therefore only about 5 millionths of a milligram. If there were any way of making even a small part of the energy latent in matter available, our supply of useful energy would be enormously increased. It may be that the sun is in a condition where such conversion is going on. Radioactive matter is in such a condition.

14. *Einsteinian Physics.*—But to return now to light regarded as suffering attraction because, being energy, it is mass. A simple calculation of the deviation of a ray of starlight passing close to the sun on its way to our eye shows that on the Newtonian theory the deviation would be 0.87″ and would fall off inversely as the distance of the periphelion from the center of the sun. (In the astronomical work of determining parallaxes, 0.87″ is a very large quantity, larger than any stellar parallax.) This was Einstein's first estimate. When he had formulated his complete theory, a new calculation showed that, on the curved space-time hypothesis, the deflection should be twice as much, namely, 1.75″.

The solar eclipse of last spring gave an opportunity to measure the deflection which was found to be in satisfactory accord with the new theory, not with the ordinary Newtonian. The report of these findings as presented at a recent meeting of the Royal Society was the occasion for the newspaper interest in the obsolescence of Newton.

Another fact that was really the cause of an early widespread interest in Einstein's work on the part of astronomers was that from his theory a calculation of the motion of Mercury showed an advance of the periphelion of 42″ per century, the amount that had so long defied satisfactory explanation.

A third consequence of the theory is that light originating near a great mass such as the sun should be of lower frequency than if originating near a small mass like the earth; the lines in

the sun's spectrum when compared with laboratory standards should be shifted toward the red by a minute amount much as if the sun were traveling away from the earth.

This prediction has been subjected to a most searching experimental analysis at Mt. Wilson and remains unverified, though if the effect existed, it ought to have been found. The phenomenon may ultimately be found or its absence satisfactorily explained. On the other hand the deflection of rays of light by the sun, as solar eclipses are again searched, may be found to be absent or may be attributable to refraction in an extremely tenuous solar upper atmosphere.

There are, moreover, some cosmographical speculations by Einstein relative to the finiteness of our sidereal universe, and the distribution of matter in it, which I should mention if there were time. Cosmography, however, has become a large science in itself, in the last few years, with tolerably definite and highly interesting conclusions which should be treated in their entirety, and to this whole the present contributions of Einstein's theory are, of course, small.

15. *Einsteinian Philosophy.*[8]—Our interest here is primarily with the philosophical and there is one fundamental view of Einstein's which seems to have been his guiding star through his earlier and his later relativity. In 1905 he desired to construct a theory independent of the rest or state of uniform motion of any observer—certainly a philosophical ideal.

Later he introduced his "postulate of equivalence" wherein he states that from observations in a closed system (our railroad train) an observer should be unable to tell whether he were at rest in a gravitational field or in motion with a uniform acceleration. Thus not only can the isolated observer not determine his absolute motion (velocity), he can not tell how much of the force he feels may be due to attracting masses and how much of it to his own acceleration. This is a reasonable philosophic idea or physical assumption.

We all know that we feel lighter in an elevator moving with a downward acceleration whether this be in starting downward or in stopping toward the top of a rise. And we have all heard the more complicated conditions arising in flight, and the indetermination which arises thereunder, discussed by aviators when telling of flights in clouds.

One can see in the equivalence postulate the germ of the

[8] Reference should be made to *Science*, 51, Jan. 2, 1920, pp. 8–10, where Einstein gives his own statement. See also "Relativity Theories in Physics" by R. C. Tolman in a forthcoming number of the *General Electric Review*, Schenectady.

idea that gravitation is a fictitious force, and the possibility that an observer by his own measurements would come to some space-time conception which in itself should cover the phenomena ordinarily attributed to gravitating masses.

Another proposition which guided Einstein was that the laws of nature, whatever they be, should be expressible in such a manner as to remain valid when any system whatsoever of time and space coordinates be used. This insistence on a general invariantive or covariantive statement of law is responsible for much of the mathematical difficulty in the formulation of the theory, but we have the author's testimony that it was of considerable heuristic value.

The relativity principle whether old or new (1905) regarding velocity and the equivalence postulate regarding gravitation and acceleration are types of a "philosophy of ignorance" such as is often met in the theory of probability, in the "principle of sufficient reason," in arguments from symmetry, etc. It does valiant service for the wise, but is a dangerous tool for the really ignorant.

This method in science may be called the philosophic if it be desired to have a phrase contrapuntal with the scientific method in philosophy[9] concerning which Mr. Hoernle spoke to us at our last meeting. The meaning of the adjective is, however, not positive but comparative and reaches out toward the superlative in either case only as the adjectives philosophic and scientific are conceived in their narrowest senses.[10]

16. *Man's Place in Nature.*—Man's place in physical Nature used to be central. His earth stood still and everything re-

[9] The method, roughly, of Russell and Whitehead. Undoubtedly life is too short to cast everything into a rigorous mould and much would be lost by an insistence on the method. In mathematics itself the extreme rigorous and logical method is not pursued except in restricted fields or when dangerously critical problems are attacked. But a well-trained mathematician or mathematical physicist must to-day have had some education in extreme rigorous analysis that he may come to know the pitfalls that are in the way of careless workers and avoid them. A similar training in the scientific method for its educational value should be required of students of philosophy; it saves time in the long run.

[10] Although Einstein's method has been called philosophical, one should not infer that Einstein is technically a philosopher or that philosophical technicians will agree as to the system of philosophy that is fortified by his conception of Nature. Mr. Hoernle has called my attention to some spirited correspondence between Whitehead and Walker in the *Nation* (London) for Nov. 15, 29 and Dec. 13, 27 (1919) wherein the former claims that Berkeley has been avenged and the Aristoteleans put to rout, while the latter finds that only now has Aristotle completely come into his own. Alas, poor Yorick!

volved around it and him, and his god or gods sat off where they were put and were pleased by his frankincense. And he saw everything he had made and behold, it was very good, and when he had thus done and been satisfied with the goodness thereof he rested,—upon his Carnegie pension, or otherwise.

How near to this point of view some metaphysical idealists may still be I do not venture to surmise. Certainly the perusal of some presentations of the more extreme idealism gives the scientist the impression that there have been those who would convert that reverent and realistic scientific lullaby

> Twinkle, twinkle, little star;
> How I wonder what you are
> Up above the world so high
> Like a diamond in the sky.

into some such blasphemous conceit as

> Twinkle, twinkle, little star;
> I know what you really are—
> Just a greedy summer fly,
> Creature of my inner eye.
> Nibbling at that hunk of cheese
> Half a mile beyond the trees.

Probably none of their ilk remain.

Man's place to-day in physical Nature is far from central. He should be decidedly humble. He knows infinitely little and what knowledge he has is for the most part either a partial understanding of discrete facts or a conventional correlation of different facts based not upon ultimate truth but upon the brief convenience of the leading minds of his time,—to the lesser minds the convenience of the leaders may be a serious inconvenience.

In Homeric times the earth was flat. A thousand years later it was round, first by philosophic or mystic fancy, then by indisputable proofs of Aristotle, measured with accuracy by Eratosthenes and charted by Ptolemy. For a thousand years under Christianity the earth was again flat, and no "good" man could think otherwise. Since a bare five hundred years the world has been round again, first for martyrs and then for all. Who shall say that it will not again become flat? Viewing history and the prehistoric record as a whole who dares predict that some barbarian horde, some incendiaries of libraries, some religious bigotry will never wipe out present knowledge, replacing it for long periods of time by some earlier doctrine that we now deem less convenient, untrue.

Aristarchus had a good heliocentric theory of the world;

why should Hipparchus have chosen the geocentric—the greater reversing the lesser scientist? Why should Ptolemy have continued the error? What seemingly sound scientific doctrines of to-day are the geocentric systems of Hipparchus and Ptolemy, overriding, reversing the saner positions of some humble Aristarchus of a generation ago who may yet wait centuries for vindication? May it be the luminiferous ether? Einstein is quoted as saying there is no ether. Is the early corpuscular optics to return, modified of course sufficiently to account for our present continuous optics, and shaped to cover our discontinuous optics of quanta? I do not know.

The absolute and the universal, though perhaps a guiding inspiration, remain mere emotional aspirations. Under the analysis of the last century even our logic broke down before the paradox of "the class of all classes," and however much we may push off this contradiction by finer analysis, I do not believe we shall be rid of it until we abandon such phrases as the class of all classes,—any more than the mathematician was rid of his difficulties with the simplest type of infinity until he insisted that this was no infinite except as an indefinitely increasing finite, so that the static infinite became the kinetic finite.

We are acquiring and discarding, learning and forgetting, and at any time there is nearly an equilibrium between import and outgo; for some centuries we gain, for others we decline with a fall far more swift and precipitous than the arduous climb.

Not the survey of the latest theories, nor estimates of the immediate future, nor yet the study of the past few centuries will suffice to ground a philosophy. Several millenniums are necessary. On the whole we seem to be getting on. At least we must have faith to carry on.

And so for a philosophy I turn back to the first of the metaphysicians whose doctrine, as I understand it, may be phrased in the words of the passing song, "We don't know where we're going, but we're on our way." Far better so than "All dressed up and nowhere to go"—yes, worse, left behind, in the majestic march of Nature and of man's living thought upon it.

THE NEED FOR A MORE SERIOUS EFFORT TO RESCUE A FEW FRAGMENTS OF VANISHING NATURE[1]

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IN these days of anxiety and suffering, when large populations are on the verge of starvation, and revolution threatens us within our own gates, it might not seem especially opportune to urge the claims of any movement not immediately concerned with the welfare and safety of mankind. This is perhaps particularly true of any proposal to render unavailable for human consumption considerable fragments of what we are wont to term our "natural resources." Indeed, the most plausible objection on the part of those who are engaged in the commercialistic exploitation of these resources, would be this one, that everything in the world must be made of some "use" to humanity. Such talk seems to breathe of the spirit of altruism, and it also harmonizes very well with the dominant utilitarianism of the day.

And so it comes about that most of the "conservation" which is being preached in these days is the conservation of our *resources*, of our coal and our lumber and our water-power and our fisheries and what not. Heaven knows that all these belated reforms are necessary enough. But there is another sort of conservation which has thus far received utterly inadequate attention. I refer to the conservation of nature—nature as a source of scientific knowledge and of the highest esthetic enjoyment of mankind.

Some of you will think at once of our National Parks and our National Forests, of our Audubon Societies and our game-laws, and will conclude that the needs which I speak of have already been sufficiently well provided for. I have little doubt that a large proportion of even that small minority who have any real interest in the preservation of nature and of wild life soothe themselves with this reflection that the existing agencies are quite adequate for the purpose.

We can not give too high praise to those individuals and

[1] Lecture delivered before the California Academy of Sciences, San Francisco, December 3, 1919.

organizations which have thus far succeeded in checking, however slightly, the destruction of our natural scenery and of the native fauna and flora of our continent. But it is utterly foolish to imagine that these slight beginnings are sufficient to avert a great and irreparable catastrophe.

I think that no harm can come from our endeavoring to indicate, in a general way, the sort of things which we should like to accomplish, had we the power. This, even though our aims, in some respects, may prove to be impossible of realization. There are two equally important lines of effort, prompted by two quite distinct motives. The first of these motives is the scientific one.

Biology is the science of life, of the totality of plants and animals which occupy or have occupied the face of our planet. One might readily conclude, however, that there are zoologists, and some of them occupying high positions, who would not be greatly disturbed if the entire natural fauna and flora of the earth, with a few specified exceptions, should be destroyed overnight. If we left them the various laboratory types which are dissected or sectioned in "Zoology 23," along with the fruit-fly and one or two domesticated mammals and birds, I am not sure but they would rest peacefully in the belief that all future needs of their science had been fully provided for. I can not speak with any such confidence for the botanists, but the fact that neither they nor the zoologists are making themselves heard from at all audibly in this matter, seems evidence of the comparative indifference of both groups of biologists to the world-wide assault upon living nature.

It would hardly seem necessary to justify to scientific readers the importance of saving from destruction the greatest possible number of living species of animals and plants, and of saving them, so far as possible, in their natural habitats and in their natural relations to one another. And this is not primarily in order that the ornithologist, the entomologist, and the rest, shall gratify their traditional passion for naming species. It is because some of the most important problems of biology are concerned with relationships, and can only be solved by comparisons. Comparative anatomy was to Darwin, as it is to us, one of the chief fields to which we must look for our evidences of organic evolution.

Another of these fields is that of geographic distribution. It is not only the broader questions involving the larger subdivisions of the animal kingdom—the orders, families and genera—which are of importance here. One of the most

promising lines of attack upon the still unsolved problem of the "origin of species" is to be found in the study of our *incipient species, i. e.,* our "subspecies" or geographic races. If most of these are shortly to be exterminated, and many others to be displaced from their natural habitats, we shall have lost a highly important clue to the initial stages in the formation of species in nature.

Then, too, what shall we say of the modern science of ecology, which concerns itself with the totality of animal and plant life in particular regions, viewing these whole assemblages as being themselves organisms, having a definite cycle of development, like an individual animal or plant. It is significant that the ecologists, of all biologists, appear to be most active at present in the campaign for the preservation of natural conditions.

But aside from these broader considerations, can the laboratory biologist feel quite certain that even the "types" chosen for his class-work, or the "material" for his own researches will be eternally safe from depletion without any effort on his part. We have for some years been hearing of the difficulty of obtaining such classical objects of research as the sea urchin and some other organisms for the laboratories at Woods Hole. It would seem as if the biologist, like the hunter and the fisherman, had been seriously jeopardizing his own future supply of game.

The second great motive for the conservation of nature is that which, for a better name, we might call the esthetic one. I think, however, that this word, if employed in the present connection, would convey my meaning quite inadequately. For the love of nature includes vastly more than the appreciation of natural scenery. It includes that deep-rooted feeling of revolt—not yet quite dead in most of us—against the noise and distraction, the artificiality and sordidness, the contracted horizon and stifled individuality, which are dominating features of life in a great city. Now it may be that such a feeling of revolt may represent merely a passing phase in human development, indicative of incomplete adjustment to a really higher plane of existence. It may represent the welling up of atavistic, antisocial tendencies, which it is our duty to sternly repress. Perhaps the highly socialized man of the future will gather more inspiration from the mad crush of the home-bound subway crowd in New York City than he will from the solemn majesty of the desert at sundown.

Perhaps all these things are true, but I should be sorry to

think so. If this is the real trend of human evolution, we who represent the "unfit" type, may well pray for a speedy extermination. I suspect that for many of us students of nature the appeal of natural scenery is of the same kind, though vastly more compelling, than that of either music or poetry.

I am quite aware that I am exposing myself to the charge of leaving the field of scientific discussion and of resorting to sentiment and rhetoric. This in a sense may be granted. But I doubt whether any harm can come from our appealing to both motives—the scientific and the sentimental—in a discussion of this many-sided question. Who would be willing to say, moreover, that these two motives are wholly distinct from one another? Is there so little in common between the naturalist and the nature-lover? Perhaps most of us would wish to be regarded as both. However that may be, the two have a common interest in promoting the enterprise before us, even though they may speak a widely different language.

The need for prompt and drastic action to save our native fauna, especially the birds and mammals, has been ably and forcibly set forth by various recent writers. It is scarcely necessary for me to rehearse the gloomy chronicle of extinct and vanishing species which has been recorded by Hornaday[2] and others. Let us not, however, focus our attention too exclusively upon these relatively few examples which are so conspicuous—the mammals and birds which are sought for as sources of food or feathers or fur.

Many states retain but few traces of their original assemblages of animals or plants in general; many possess little that can in any true sense be called natural scenery. Forests are vanishing, brush land being cleared, swamps drained and the desert irrigated. "Reclamation" is being pushed forward with an almost religious fervor.

Cattle and sheep are grazing everywhere upon our meadows and hillsides, with a resulting diminution of that wealth of resplendent coloration which was formerly the glory of California. Not only are our wild flowers disappearing through the agency of grazing animals, but the same is true of various birds, whose nests are built upon the ground.

No agency of civilization has perhaps been more potent in bringing large numbers of our people into close contact with

[2] "Our Vanishing Wild Life," New York, Chas. Scribner's Sons, 1913; "Wild Life Conservation in Theory and Practice," New Haven, Yale University Press, 1914. See also the able and forceful article by W. G. VanName, entitled "Zoological Aims and Opportunities," *Science*, July 25, 1919.

nature than has the automobile. But there is another side to the story. The automobile is fast opening up to the week-end excursionist the remotest mountain fastnesses and the wildest solitudes of the desert. Game is shot, much of it doubtless contrary to law, wild flowers and native shrubbery are gathered in reckless profusion, disfiguring rubbish is scattered broadcast, and fires are started which burn over thousands of acres of brush or forest land. Most of these fires, according to professional foresters, are due to carelessness. I think I am safe in adding that most of them have been made possible by the automobile.

The splendid redwood forests of the northern California coast belt—perhaps the finest forests on the American continent—are falling before the axe and the saw of the "lumber king" and the air for much of the year is hazy with the smoke of the burning brush and trees which have to be thus removed before the fallen giants can be cut up and dragged away for the market. The result is a scene of appalling desolation for years to come. When these forests are gone—as they will be, save for a few remnants—our fertile-brained inventors will discover quite acceptable substitutes for redwood lumber, and the building business will continue "as usual." But we shall never find any acceptable substitutes for the redwood forests, which it took nature thousands of years to produce. It is true that in the case of this particular tree a second growth may reforest an area which has been logged over or damaged by fire. But this is a slow process, and we can not be sure that the same plant associations will establish themselves as existed previously.

Even the desert, which has long furnished interesting problems to the naturalist, as well as inspiration to the poet and the painter, seems doomed to wholesale invasion and exploitation. To make the desert "blossom as the rose" has for ages been looked upon as typical of man's conquest over nature, and the wonderful achievements in our own Southwest stand in the front rank of such efforts. But we can not overlook the tragic side of the picture. The limitless vistas of picturesque desolation lose much of their mystery when we find that they are threaded in all directions by automobile roads, and when the eye is everywhere confronted by scattered rectangular clearings, due to the fruitless efforts of would-be desert farmers. The highly interesting and picturesque plant associations in the western portion of the Mojave Desert are being rapidly destroyed by so-called "settlers" who are probably not getting

enough out of the land, in most cases, to pay expenses. The weird and beautiful tree-yucca, a plant so typical of our California desert landscape, is now being largely used for various commercial purposes. I know of at least one company, organized with the particular object of exploiting these yucca products. As this is a tree of extremely slow growth, we may expect its practical extinction within large areas in the near future.

Where, then, has our discussion thus far led us? Are we to check the growth of population, arrest the march of progress, and withdraw from a large part of the land which we have occupied? Such a proposal is, of course, ridiculous. What is worth serious consideration is an insistence upon the conservation of our fauna and flora and natural scenery to an extent hitherto not contemplated by our people or our government.

Large tracts of land, representing every type of physiography and of plant association, ought to be set aside as permanent preserves, and properly protected against fire, and against every type of depredation. Here would be included desert and chaparral, swamp land and seashore, mountain and prairie. All this would doubtless cost vast sums of money, but what is money for? The question is really one of relative values.

Instead of game-laws, we should have a nearly absolute prohibition, both within and without these reservations, of the shooting of every wild mammal or bird not definitely known to be harmful to man. Exceptions might be made in certain cases, but only after careful consideration by competent and disinterested persons.

All lumbering operations should be under the supervision of the government. Throughout large tracts, such operation should be absolutely prohibited, and where permitted, the trees should not be removed faster than their natural rate of replacement. Exception is of course to be made of land which is to be permanently cleared for agricultural purposes. But the question as to which areas should become farming lands, and which ones permanent forests ought to be decided by disinterested experts, with sole reference to the higher welfare of the public and of posterity, and not on the basis of purely local circumstances or the accidents of private ownership. Scientific considerations, such as the advantage of maintaining the continuity of a given forest area, should figure here, among other motives.

The fact that *all* of our redwood forests, with two unim-

portant exceptions, are now in private hands and are fast disappearing, shows how far we are from the realization of such an ideal. Fortunately, in this particular case, a public-spirited group of citizens have taken steps which seem likely to result in the reservation of a considerable tract of these unique forests.[3]

Another part of our program should be a vastly more adequate system of fire protection, and of game-law enforcement. This may be said without reflecting upon the competency of the various forest and game wardens who are entrusted with these duties at present. Many of them doubtless do the best possible with the utterly inadequate resources at their disposal. Who can read of the continuous series of holocausts which devastate the Rocky Mountain and Pacific Coast States every summer without realizing that the means of fire protection must be utterly inadequate? The president of the American Forestry Association is quoted as saying recently (N. Y. *Times*) that although "the United States Forest Service spent more than a million dollars fighting these fires in July alone, . . . the fire protection measures in neither national, state nor private forests are sufficient to properly protect them."

At the time of the recent fire in the California Redwood Park at the Big Basin, the state forester made the statement that $140,000 had been asked of the previous legislature for fire protection during the present biennium, whereas only $25,000 had been appropriated for this purpose. He attributed the frequency and the disastrous results of forest-fires during the past season to this lack of adequate funds. We can not help wondering how the thrifty taxpayer invested the few cents which were saved him by this economy on the part of his representatives at Sacramento.

As for game-laws, it is widely believed that these are habitually violated by dwellers in the more remote sections of the state. Adequate protection would doubtless mean a much greater expense, but here again we are met with the question: would it not be worth while?

The whole problem with which we have to deal is, after all, one of relative values. What are the things that are most worth doing—and paying for? Our whole plea for the conservation of these considerable fragments of nature rests, of course, upon the *value of these to mankind.* What the wishes of the animals and plants are in this matter does not much

[3] Save the Redwoods League. For information, address Mr. R. G. Sproul, Sec.-Treas., University of California, Berkeley.

concern us. But we must recognize the existence of various standards of value, and I believe that there are standards far higher than are generally recognized and applied to this question.

Our reasoning is too often like that of the farmer who was asked why he wanted to add to the size of his farm. "So as to raise more corn," was his ready reply. Pushed by his questioner to tell why he wanted to raise more corn he said; "So as to feed more hogs." And the sale of his hogs, he declared, would enable him to buy more land, in order to raise more corn, in order to feed more hogs, and so on to the end of his natural life.

I hope I may be pardoned for quoting from another article[4] in which I have asked the question:

> What will the increased population do which is made possible by a greater food supply? It may all mean a merely *quantitative* increase in the total amount of living—by no means a self-evident advantage, according to my way of thinking. The great mass of humanity is engaged in discharging the purely vegetative functions of the social organism, in keeping alive the individual and the race, and in maintaining a certain low minimum of comfort. To merely increase the total amount of this vegetative activity in the world seems to be widely accepted as one of the chief goals of human endeavor.

Once more:

> Which is the higher aim to make room in the world for the greatest possible number of human animals, or to make the world a more interesting and intelligible [and beautiful] place to live in: to feed the belly or to feed the brain?

Again, it must be insisted that as things now go, our world is destined to be populated up to its capacity, within a comparatively brief period of time. In that day, if not before, we shall be faced with the problem of correlating the rate of reproduction with the means of subsistence under endurable conditions of life. Would it not be equally possible, and vastly more desirable, that we should strike this equilibrium some time before the inhabitable land had all been occupied? I think there can be no difference of opinion as to which of these alternatives offers the greater prospect for future human happiness. This mad rush to fill up every nook and cranny of the world is prompted in a large degree by national ambition for power; partly also by the greed of the business promoter and the real-estate shark. These are the greatest foes of any movement toward leaving the world truly habitable for the future.

[4] SCIENTIFIC MONTHLY, March, 1919.

I trust that I shall not be charged with voicing any general depreciation of what we call "man's conquest of nature." To a large extent this has been desirable; and in any case it has been the necessary price which we have had to pay for our advance beyond savagery. Many things in nature have had to be used, even though this use has destroyed their beauty and their interest as objects of scientific study. What we insist upon is a fuller recognition of the non-utiliarian motives, or, we should perhaps say, a broader conception of what constitutes *usefulness*.

Why is it that even we who claim the title of scientists are always so timid and shamefaced about declaring our real motives for the protection of living things. We must save the songbirds, because they eat up cut-worms and the seeds of noxious weeds. We must save the game-birds, in order that they may remain and be successfully hunted by future generations of sportsmen. We must save our forests as future supplies of lumber and as a protection to watersheds; we must save multitudinous other things because we may still discover uses for them now unknown.

Is all this because we feel that we are the only ones who are highminded enough to appreciate our own lofty motives, and that neither the public nor its elected representatives can be taken into our confidence? Such a pessimistic judgment may possibly prove to be warranted, but there are several reasons for working on the opposite assumption, if only as an experiment. In the first place, if the public and its representatives in legislature and congress are really as sordid as we credit them with being, our own attitude is calculated to confirm them in their sordidness. If even the savant assents to the proposition that practical utility is the only standard of value, what shall we say of the hoi-polloi? We are helping to create a background of public-opinion which is certain to block every serious move toward the reservation of large fragments of nature for non-utilitarian ends.

In the second place, all such more or less disingenuous justification of our endeavors in this direction can not fail to react upon ourselves. Can our intellectual honesty help being blunted by our habitually acquiescing in a theory of life which at the outset we must have stanchly repudiated?

The reader has doubtless long been patiently waiting to learn whether my whole effort was to expend itself in exhortation, or whether I had a definite program of action to offer. Personally, I have no very definite program; much less do I

wish to pose as a leader in a movement of such vast magnitude. Least of all do I wish to slight the large volume of important and successful work in this direction which has been accomplished by many persons, including some of our foremost citizens. If my presentation of the case should result in renewed effort on the part of some of those who share these views; or if it should attract the attention of a few who had not given previous thought to the problem, my labors will not have been vain. I fear that there is only too much justification in the charge made by certain writers that we professional zoologists of the universities have not faced our plain responsibilities in this all-important matter. Can we refute the essential accuracy of Hornaday's rather ill-natured declaration that "fully 90 per cent. of the zoologists of America stick closely to their desk-work," not perhaps "soaring after the infinite and diving after the unfathomable," as he expresses it, but nevertheless "never spending a dollar or lifting an active finger on the firing line in defense of wild life."[5]

In similar vein, Van Name writes of the "easy-going indifference and irresponsibility of those who are the only ones who can fully realize the needs and urgency of the situation, and who should therefore feel it a duty to make others understand also."[6]

Now, while I have no very definite plan of campaign to offer to those who would like to devote some of their energies to this cause, I do feel at liberty to make a few suggestions. In the first place, this is an occasion above all others, where cooperative effort is necessary. The matter should be taken up seriously by the great national scientific societies. It may be mentioned here that the Ecological Society of America already has a "committee on the preservation of natural conditions for ecological study." This committee is in possession of considerable information which will doubtless be of value.

But the work of any of these societies would necessarily be for the most part of an advisory nature. Such a program could, of course, be carried out only under government auspices. Here, several different branches of the service are to be mentioned.

1. The National Park Service, already administers an area of about 10,000 square miles, comprising fifteen parks. The latter, of all parts of the public domain, probably come nearer to fulfilling the conditions required of a nature reservation in

[5] "Wild Life Conservation," p. 184.

[6] *Science*, July 25, 1919.

our sense of the words. They are inadequate for our purposes, however, in that they include only areas of exceptional scenic grandeur. The demand for extensive tracts, representing every type of physiography and of plant association, has not thus far been met. Likewise, the national parks are preserved primarily as "public playgrounds," and the public is admitted to every portion of these lands. Such playgrounds are doubtless among the important assets of the nation.[7] But there ought to be still other tracts, in which the fauna and flora are reserved primarily for the studies of the botanist and zoologist —ones in which the native life will be more adequately safeguarded than at present. It does not seem to me utopian to try to have the National Park Service or some other bureau of the government adopt, and publicly and explicitly avow, this additional motive for reserving tracts of land from settlement or depredation—namely, the permanent preservation of the native fauna and flora by reason of their value to science, and to the higher interests of generations to come.

2. The National Forest Service, which administers nearly a quarter of a million square miles, an area about as large as the New England and Atlantic States combined. One might be disposed to think that in setting aside these huge areas, the government had done far more than the most sanguine conservationist would have a right to ask. But we must note several important drawbacks, from the point of view of the scientist. To begin with, the national forests are located chiefly in the more elevated and mountainous regions of the country. Very little of the lowland forests—none, indeed, of the coast redwoods—are thus included. In the second place, lumbering, although on a restricted scale, is permitted in the National Forests, as are also grazing, hunting and camping. All of these last conditions are quite incompatible with the interests of botany and zoology, and they are likewise incompatible with the aims of those who would like to retain great tracts of virgin forest as a heritage for the future. Would it not be possible to reserve certain tracts—wisely chosen by distinterested experts—from which the lumberman, the hunter and the cattleman should be forever excluded?

3. The United States Biological Survey has established a considerable number of bird and game refuges, in which the

[7] Especially to be commended is the plan to have trained field naturalists detailed for duty in these parks during the summer season, for the purpose of giving instruction to such visitors as may be seriously interested in the natural history of the region.

shooting or molestation of birds is prohibited. There are 74 such refuges thus far established, these, in every instance, being selected with reference to their value as nesting grounds. Attention must be called, however, to the lack of any guarantee as to the permanency of such sanctuaries. Two of the most important of them, lying within Oregon and California, were set aside as bird refuges by President Roosevelt in 1908. One of these, Lower Klamath Lake, has been recently seized upon by the Reclamation Service, and is already practically ruined as a breeding ground for water-fowl. This is all the more reprehensible, since the director of the Reclamation Service has recently admitted, after investigation, that the potential value of these marsh lands for agricultural purposes is doubtful.[8] The second of these reservations referred to, that of Malheur Lake, seems about to undergo the same fate.

4. Aside from these branches of the federal government, we have certain departments of various state governments which administer more or less extensive state forests and game refuges.

The problem before those biologists who are interested in the aims above set forth is to develop an organization which will be able to mediate between themselves and the various state and national agencies through which such ends could be accomplished. An entirely new society might be organized for this purpose, but the general sentiment of scientific men at present seems to be against multiplying these societies. It has been suggested by one of my correspondents that a new section of the American Association might be created for this purpose. Another suggestion is that the National Research Council might properly serve as a clearing-house for such efforts. I am not in a position at this time to make a recommendation in the mattter. The main thing at present is to induce the various scientific societies, national and local, to take the matter up and discuss it seriously.[9] This might result in the formulation of a wise plan of action and it would at least, serve a good purpose if it succeeded in rousing from their present apathy many of those who could be of considerable service in the movement. Wise leadership is of course necessary, here as everywhere.

[8] Cited by W. L. Finley, state biologist of Oregon, in *Portland Oregonian*, October 26, 1919.

[9] I must again urge the fact that the Ecological Society of America has already made a beginning in this direction.

Two further comments seem to me worth making before I close this rather long harangue.

One is that we should state our objects and aims with absolute frankness. If we believe, as I hope we all do, that scientific, esthetic and higher humanitarian considerations are strong enough to stand upon their own feet, let us not justify every step that we take by appeals to economic and crassly utilitarian motives. If we favor, as perhaps many of us do, a practically total prohibition of the hunting of harmless species for sport, let us not league ourselves with the sportsmen themselves, and pretend that we are merely trying to save the "game" for future generations of hunters. It is certainly an unfortunate circumstance, to my mind, that most of the present enforcement of game-laws is paid for out of funds derived from the issuance of hunting and fishing licenses.

The second and last of my comments is a repetition of the warning that this question is an urgent one, and that emergency measures are necessary. With an increasing population, modern implements and vastly more efficient means of transportation, more destruction can be wrought in a single year than was formerly possible in a decade. Then too, we have recently had the inevitable raid upon our resources of all sorts necessitated by the late war, and the equally inevitable raid which is bound to result from the post-bellum problems of reconstruction. A bill is now before Congress, setting aside five hundred million dollars from the treasury for the purpose of "reclaiming" a large part of such usable land as has not yet been developed agriculturally. This measure has been introduced ostensibly in the interest of the returned soldiers.

I do not know how many of these deserving men have expressed any desire for farming lands. The sponsor for this bill may have data on the point. But in any case, a certain considerable fraction of our unreclaimed land ought to be reserved from settlement. Such a step would be in the interest both of science and of a truer humanitarianism which sees even greater benefits to our race than those which may be conferred by lumber mills and irrigation projects.

THE ORIGINS OF CIVILIZATION[1]

By Professor JAMES HENRY BREASTED
THE UNIVERSITY OF CHICAGO

LECTURE TWO

THE EARLIEST CIVILIZATION AND ITS TRANSITION TO EUROPE, III

AS the Greek nomads ceased to wander and gradually shifted to a settled town life, they found Phœnician merchandise in every harbor town. The very garment which the Greek townsman wore he called by a Phœnician name (*chiton*) as he heard it from the Oriental traders along the harbor shores. As he continued to receive these products of Oriental art and industry, the Greek slowly learned the craftsmanship that produced these things. Indeed there is every indication that there were plenty of Phœnician workshops on Greek soil. Meantime the Phœnicians or their kindred the Arameans had long since devised an alphabet, based on Egyptian writing, and were thus employing the first system of writing made up exclusively of alphabetic signs.[28] Continuous business intercourse with the Phœnician craftsman and merchant naturally impressed upon the Greek what a great convenience the Phœnician possessed in his written records of business. Thumbing the Phœnician's papyrus invoices, the Greek tradesman eventually learned the meaning of the curious alphabetic signs, and then began to use them himself for the writing of Greek words, employing some of the

[1] Delivered before the National Academy of Sciences in Washington, D. C., April 28 and 29, 1910, as the seventh series of lectures on the William Ellery Hale Foundation.

[28] The origin of the so-called Phœnician alphabet and its transmission to Greece form a difficult problem, far more complicated than the above simple statement would indicate. The solution of the problem has been greatly furthered by the discovery of a new script in Sinai, which has been brilliantly employed by Alan. H. Gardiner, "The Egyptian Origin of the Semitic Alphabet," *Journ. of Egyptian Archæol.*, III., Part I. (Jan., 1916), with additional observations by A. E. Cowley, "The Origin of the Semitic Alphabet," *ibid.* See also H. Schaefer, "Die Vokallösigkeit des phoenicischen Alphabets," *Zeitschr. für aegyptische Sprache*, LII., 1915, 95–98; R. Eisler, "Entdeckung und Entzifferung kenitischer Inschriften aus dem Anfang des zweiten Jahrtausends vor Christo im Kupferminengebiet der Sinaihalbinsel," *Biblische Zeitschrift*, XV., 1918, 1–8; K. Sethe, *Nachrichten der kgl. Goett. Gesell. der Wissensch., Phil.-histor. Klasse*, 1917, 437ff.; and Breasted, "The Physical Processes of Writing in the Early Orient and their Relation to the Origin of the Alphabet," *American Journ. of Semitic Languages*, XXXII., 1916, 230–248.

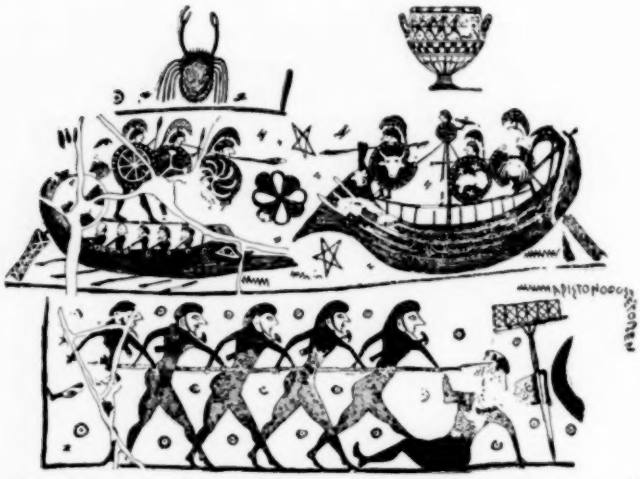
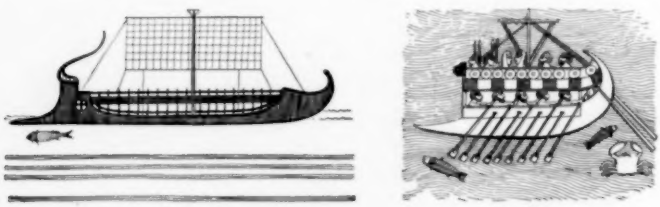


FIG. 117. PAINTINGS ON AN ARCHAIC GREEK VASE SHOWING THE EARLIEST KNOWN SIGNATURE OF A GREEK VASE-PAINTER. The vase-painter's signature is at the extreme right end at the top of the lower row. It reads "Aristonothos made it," and dates about 700 B.C., at a time when the Greeks were just learning to use Phœnician writing.

signs as vowels, which were not represented in the Phœnician alphabet.

By 700 B.C. the Greek potters were writing their names, like trademarks, on the vases they produced (Fig. 117). But the Greeks soon found the Egyptian paper offered them by the Phœnician merchants of Byblos the most convenient writing material, and they called it *byblion* or *biblion* after the Phœnician port from which it came, as we call Chinese porcelain "china" or rich textiles originally from Damascus "damask." This word gave rise to the various words for library used by a large part of Europe, like the French "bibliothèque"; and our



A B

FIG. 118. AN EARLY GREEK SHIP (LEFT) AND THE PHŒNICIAN SHIP FROM WHICH IT WAS MODELED (RIGHT). After the 15th century B.C. the Phœnicians seem to have introduced a change in the earlier model of their ships (Fig. 116), altering the high bow into a beak which was below the surface of the water. Whether this change was of Phœnician origin or not is a little uncertain. The Phœnician model above (right) is from a relief of Sennacherib, showing that the Assyrians adopted Phœnician shipping, as did the Persians also. A large proportion of the Persian ships at Salamis were Phœnician. (From the author's "Ancient Times," by permission of Ginn & Co.)

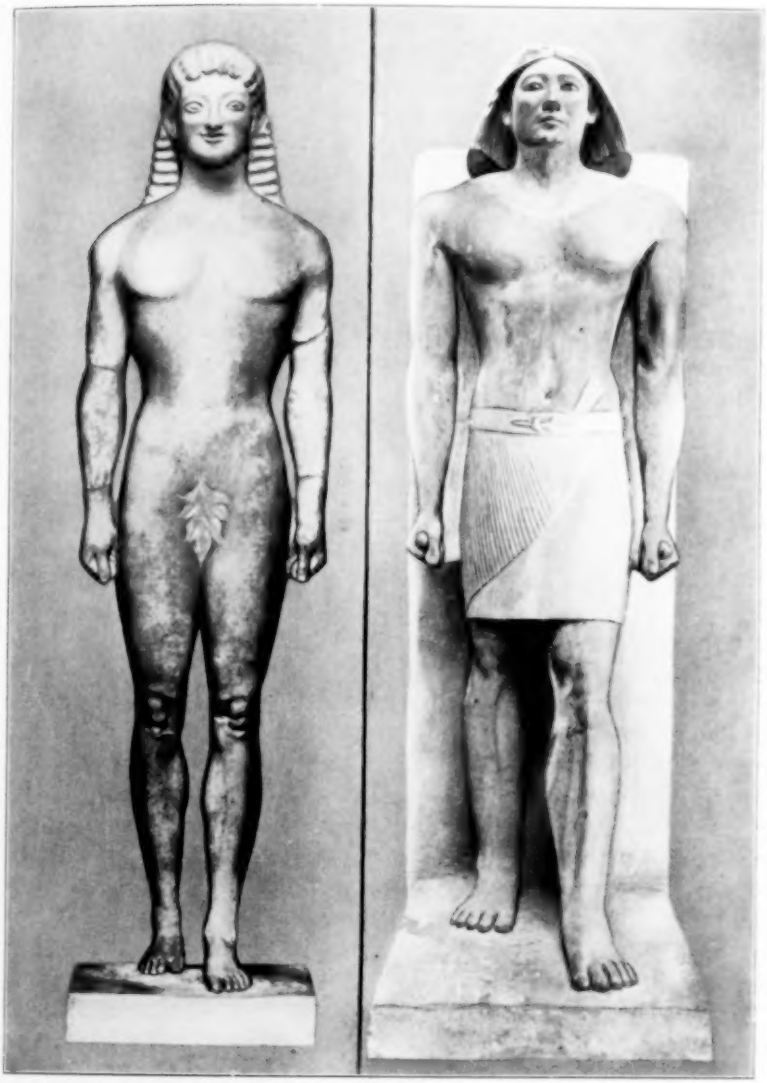


FIG. 119. ARCHAIC GREEK STATUE AND EARLY EGYPTIAN STATUE BY WHICH IT WAS INFLUENCED. The similarity, or we may say actual identity of posture, even including the left foot thrust forward, shows clearly that this archaic Greek sculpture grew up under Egyptian influence. (From the author's "Ancient Times," by permission of Ginn & Co.)

own word "Bible." Another word then commonly used for Egyptian paper was "papyrus," which with loss of the classical ending "us," and change of a single vowel has given us our word "paper." Thus after the destructive Greek invasion had crushed out the earliest literary culture that had arisen in Europe, both writing and its physical equipment were again

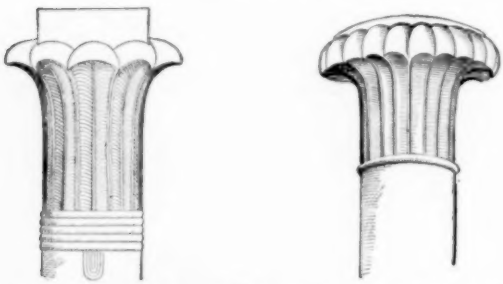


FIG. 120. EGYPTIAN PALM CAPITAL AND HELLENISTIC PALM CAPITAL COPIED FROM IT. (From the author's "Ancient Times," by permission of Ginn & Co.)

introduced into Europe from the Orient. Such contributions from Oriental life make it perfectly just to say that Europe was at that time receiving civilization from the Orient *for the second time.*

Meantime the Greeks had rapidly learned shipbuilding and navigation from their Phœnician competitors (Fig. 118). In doing so they adopted a new Phœnician model with beaked prow, quite different from the old Ægean model from Egypt (Fig. 84) with both ends turned up. This again illustrates how little of the old Ægean culture had been able to survive the Greek invasion. As the Greek maritime ventures extended to all ports of the eastern Mediterranean, Greek merchants and gradually also Greek travelers, came into direct and first-hand contact with the vast fabric of civilized life in the Near Orient, especially after 600 B.C. The travels of Solon, Hecatæus, Herodotus and Plato will occur to very reader. It should be remembered that in the times with which we are dealing the Greek citizen could walk entirely across a town like Athens or Ephesus in five or six minutes, and there was not a Greek city in existence which could not be traversed from edge to edge in ten minutes or less. When the Greeks first visited the Orient all Greek buildings, including the temples, were of sun-dried brick, and the supports or piers were of wood. As to statues, a wooden head surmounting a post draped with clothing was enough.

Under these circumstances it is not remarkable that archaic Greek sculpture shows unmistakable evidences of Egyptian influence (Fig. 119). The impression of the magnificent cities of Egypt and Asia upon the minds of travelers like Hecatæus and Herodotus was not exhausted in literary expression alone. Greek builders must likewise have seen these cities and added definite impressions as well as sketches to the vague references to the splendors of the Orient with which all Greeks were

familiar in the Homeric poems. Greek architecture then responded sensitively and promptly to the tremendous stimulus of the vast architectural monuments of the Orient. Such tangible examples as the Egyptian palm capital, which we found in the pyramid temples in the twenty-eighth century B.C. (Fig. 83), copied by the architects of Pergamum in later times (Fig. 120), show that the diffusion of Egyptian architectural forms Europeward is a clearly demonstrable fact. Such evidence raises beyond doubt the Egyptian origin of the Greek Doric column (Figs. 121–122). Puchstein long ago made perfectly clear the Oriental origin of the Ionic column, and to such determination of the Oriental source of the individual column, Doric and Ionic, it is of great interest to add also that of the arrangement of assembled columns around an interior court. Such a complex architectural creation is by no means an obvious concept, which could arise independently on both sides of the Mediterranean. The ancestry of the Hellenistic colonnaded court becomes perfectly evident when we place such a court, as found in a Pompeian house, side by side with the Egyptian architect's temple court of the twenty-eighth century B.C. (Fig. 123). It can not be doubted, either, that the Hellenistic architects received the idea of their clerestory hall, which they called a "basilica," from the great colonnaded clerestory halls of the Egyptian Empire temples (Figs. 94 and 95), which thus became the ancestors of the basilica cathedrals of Europe (Fig. 124).

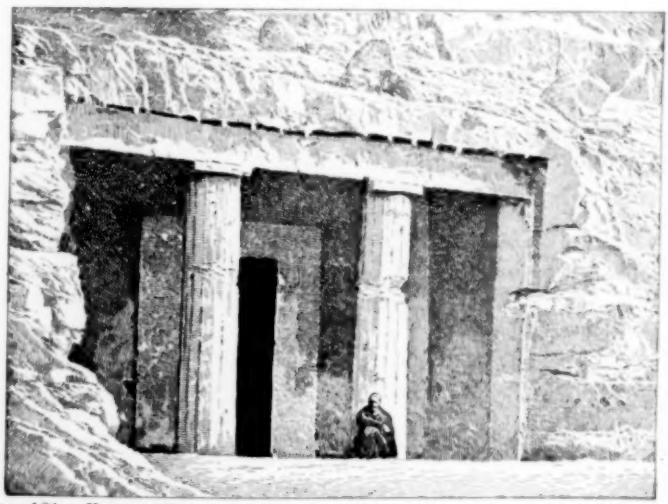


FIG. 121. FLUTED STONE PIERS OF AN EGYPTIAN TOMB A BENIHASAN. (19th century B.C.) These piers, which the Egyptians never adorned with a capital, were the ancestors of the Greek Doric column (Fig. 122).

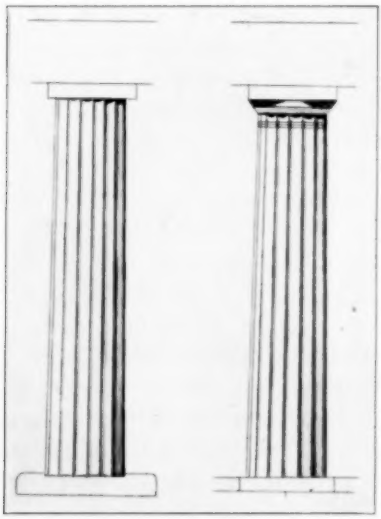


FIG. 122. THE OLD EGYPTIAN FLUTED STONE PIER AND THE GREEK DORIC COLUMN WHICH DESCENDED FROM IT. (From the author's "Ancient Times," by permission of Ginn & Co.)

Although it carries us chronologically far down the centuries, it is appropriate here to suggest a great architectural synthesis which I believe has not yet been made. The outstanding features of the Assyrian palace front, with its imposing central arch and lower arches on each side, were continued in the Parthian palace façade (Fig. 125, No. 2). It can not be doubted that Roman architects, seeing such structures in the Near East, drew the Roman triumphal arch from this source (Fig. 125, No. 3). Now when we recollect that in its nave and side aisles the clerestory hall presents a tripartite arrangement of floor, colonnades and roof, we see at once that the three arches of the old Assyrian palace front will answer to the front of the clerestory hall, part for part; the tall arch in the center corresponding to the high nave of the hall, while the smaller arches on each side correspond to the lower roof over the side aisles. In putting up a Roman triumphal arch as the front of the basilica cathedral, the architects of Europe were combining ancient Asia and Egypt.

It is further of great interest to observe that the tower with which the Christian cathedral was eventually embellished was likewise derived from the East (Fig. 126). The Hellenistic architects had found the model of their great lighthouse tower at Alexandria, the Pharos, in the old Sumerian temple towers of Babylonia. From such towers both Islam and Christianity

finally drew the spires with which they adorned their sacred buildings. Thus Christianity, itself of Oriental origin, was housed in great sanctuaries, the fundamental elements of which had likewise come out of the East.

In a sane historical and cultural consideration of the career of man such indebtedness of Greek civilization to the Orient does not in the least detract from the unchallenged supremacy which the splendor of Greek genius triumphantly attained as the sixth century B.C. advanced. To recognize this indebtedness is but to acknowledge the operation of the same cultural processes in the Ægean, which must inevitably have been operative, because there were no reasons why the Greeks should be any more impervious to external influences than any other group of peoples. The Greeks were to be the first ancient people to gain complete freedom of the mind from traditional conceptions, and were thus to make intellectual conquests far surpassing the achievements of the Orient in the world of mind; but even in this realm they were not without their debt to the

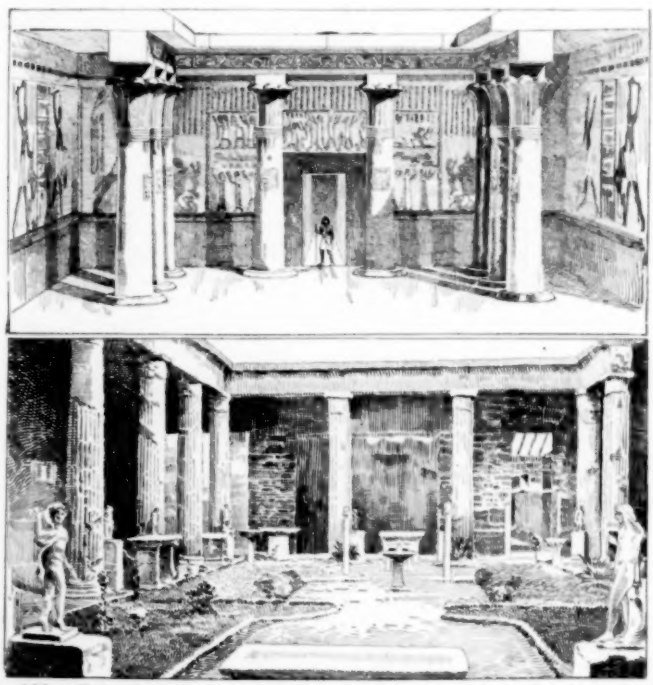


FIG. 123. THE ORIENTAL ANCESTRY OF THE EUROPEAN COLONNADED COURT. Above is the court of the temple of Sahure (Fig. 83), and below the court of the house of the Vetti at Pompeii, a building drawn from Hellenistic models in southern Italy. (From the author's "Survey of the Ancient World," by permission of Ginn & Co.)

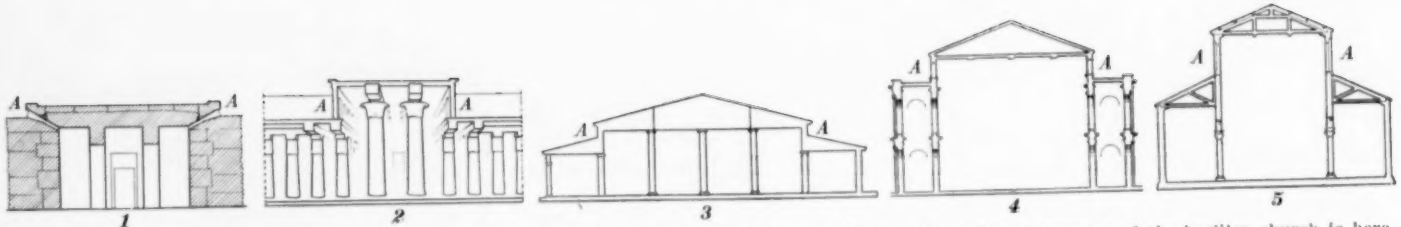


FIG. 124. DIAGRAM SHOWING THE ORIGIN OF THE CLERESTORY AND THE BASILICA HALL. The oriental ancestry of the basilica church is here evident. No. 1 is the earliest clerestory hall at Gizeh (29th century B.C., Fig. 79); no. 2 is the great Karnack clerestory hall 13th century B.C., Fig. 95); no. 3 is a Greek basilica hall of the third century B.C., showing the sloping roof necessary in a rainy country (Egypt being rainless); no. 4 is the Basilica of Julius Cæsar at Rome (first century B.C.); and no. 5 is a Christian basilica cathedral of the fourth century of the Christian Era. (From the author's "Ancient Times," by permission of Ginn & Co.)

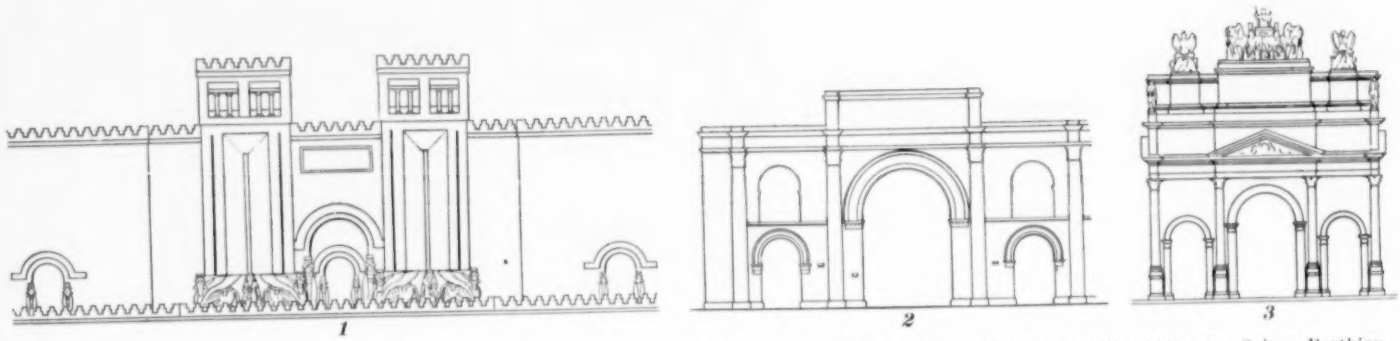
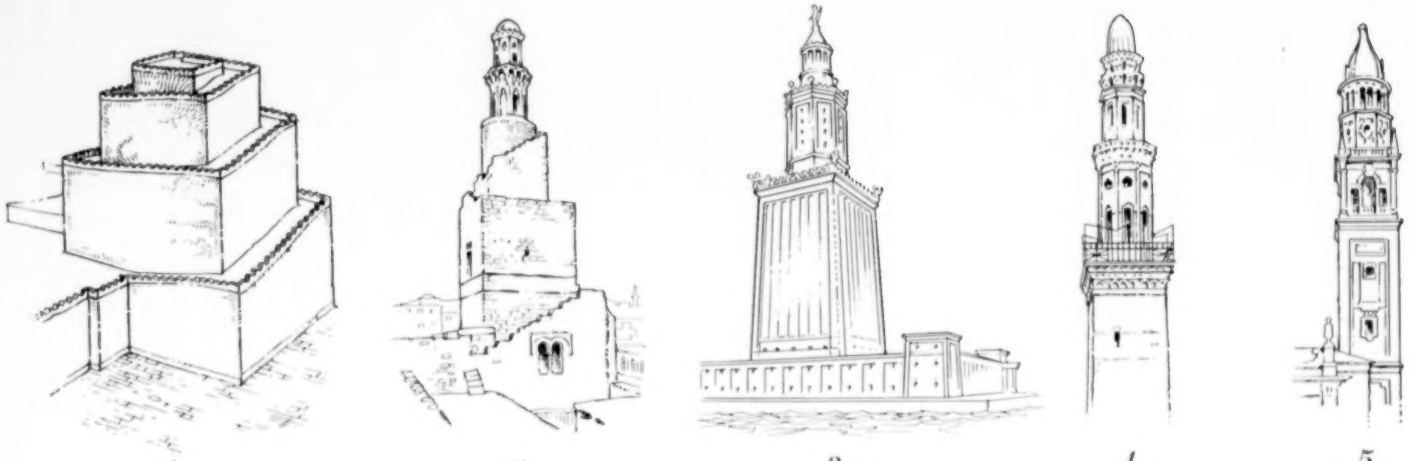


FIG. 125. THE ORIENTAL ANCESTRY OF THE ROMAN TRIUMPHAL ARCH. No. 1 is the Assyrian palace front (Fig. 111); no. 2 is a Parthian palace façade; and no. 3 is a Roman triumphal arch. (From the author's "Ancient Times," by permission of Ginn & Co.)



1 2 3 4 5

FIG. 126. THE ORIENTAL ANCESTRY OF THE TOWER IN WESTERN ARCHITECTURE, ESPECIALLY THE CHRISTIAN CHURCH SPIRE. No. 1 is the old Sumerian temple tower of Babylonia (Fig. 105); no. 2 is the minaret of the Mosque of Ibn Tulun in Cairo (ninth century A.D.), which still displays the winding ascent or ramp around the rectangular tower; no. 3 is a restoration of the Hellenistic lighthouse tower at Alexandria (third century B.C.; after Thiersch). Both nos. 2 and 3 display at the top a hexagonal member which forms the transition to a circular section crowning the whole. This is also found in early minarets of Western Asia, with a spiral ascent, as at Samarra. No. 4 is a minaret from an Egyptian mosque, while no. 5 is the spire of the church of St. John at Parmay, Italy. Both display the hexagonal and circular members at the top. (From the author's "Ancient Times," by permission of Ginn & Co.)

FIG. 127. A BABYLONIAN KUDURRU, COMMONLY CALLED A BOUNDARY STONE, BEARING EMBLEMS OF THE GODS: among them are signs later appearing in the zodiac like the scorpion and the archer.

accumulated knowledge of the natural world which they received from the Orient.

While we have thus followed the great drift of civilized influence as we can discern it especially in monumental forms which have come out of the Orient into the West, we have found that these things suggest influences less material and not so easily exhibited in visualized forms; just as the cathedral architecture of Europe, drawing its fundamental forms from the Orient, suggests the Oriental origin of the religion which it housed.

Among intellectual influences which the Greek traveler felt as he visited the Orient nothing attracted him more than the

knowledge of the future which the Babylonian priest gained by observation of the celestial bodies. As we shall see, the Babylonian observer of the heavens did gain knowledge of the future, but not knowledge of the future of human affairs as he supposed and as he assured his Greek visitors. Astral religion among the Babylonians, already in the third millennium B.C. had led them to believe that they could read the future in the anticipatory movements of the heavenly bodies. They early noted the difference in the character of the planets and the fixed stars, and they began to group the latter into constellations associated with signs such as we see on the so-called boundary stones where the scorpion and the centaur already appear among the symbols of divinities invoked to protect the title of a land-owner (Fig. 127). But there was at first no comprehensive system of the skies, including all twelve of the signs of the zodiac.

Far down into the last millennium before Christ the observations made by the priests were solely for astrological purposes. They were crudely done and furnished but very vague data. Eclipses observed long after 1000 B.C. are not even accompanied by a note of the year, while the hour, if added, will be noted as one of the three watches of the night—watches which were not of fixed length. The claim that the Babylonians of the third millennium B.C. already knew of the precession of the equinoxes has been completely disproven.[29]

Only in the last seven centuries before Christ did the Babylonians pursue the study of the heavens for chronological purposes. A large body of astronomical tablets of this period show no indication of an astrological purpose. For the first time they contain observations including the data for both time and space, and with the inclusion of these elements astronomical science began.

The tablets of this age are of two classes, *observational* and *computational*. While the *observational* tablets deal incessantly with sun and moon and the relative positions of the two, they record especially the positions of the planets. This is done by noting each planet's position with reference to the fixed stars, but at first entirely without angular measurements, and if the planet was not far to the east or west of the fixed star, the position of the planet would be indicated by the phrase, "at the place" [of star so-and-so]. Later (especially the last four cen-

[29] See the work of the able Dutch astronomer-orientalist, F. X. Kugler, "Sternkunde und Sterndienst in Babel"; on this careful survey of Babylonian astronomical documents the above sketch is chiefly based.

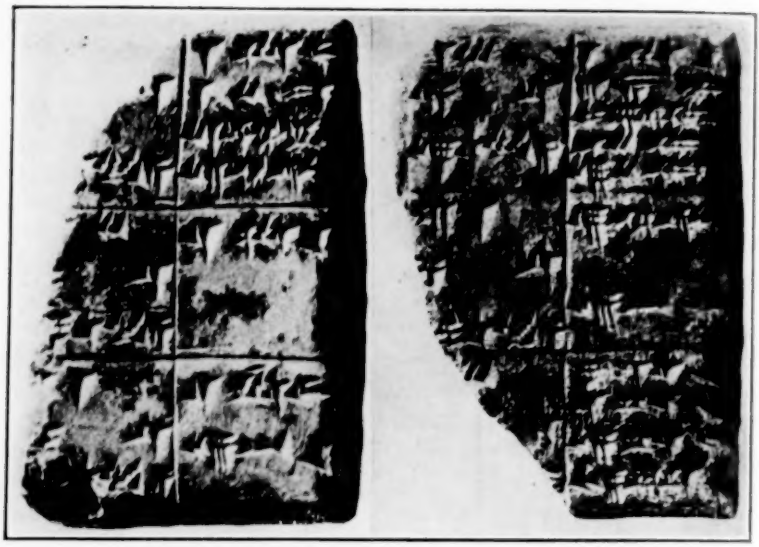


FIG. 128. CLAY TABLET PAGES FROM A BABYLONIAN ASTRONOMICAL ALMANAC FOR THE YEAR 425 B.C. (= ASIP.–424) NOW IN THE MUSEUM OF THE UNIVERSITY OF PENNSYLVANIA.

turies B.C.) angular measurements were made in "cubit-degrees and inches" (Kugler). These observations resulted in the discovery of the eighteen-year lunar period, which the Greeks called "Saros," and with the aid of these the priestly astronomers constructed the first tables of the conjunction of sun and moon (syzygy tables).

Such observations also enabled the priestly astronomers to determine with astounding accuracy the synodic revolutions of the planets. In a region of wonderfully clear skies during eight months in the year, they were able to study even Mercury, which we rarely see, with such precision that by calculations based on his heliacal rising and setting they computed his synodic revolution as 115 days, 21 hours, 3 minutes and 50.9 seconds, a result which exceeds the computation of Le Verrier by only 16.3 seconds, while that of Hipparchus is in error by nearly a minute. In the computation of the mean synodic revolution of Jupiter, the Babylonian astronomers agreed with the results of Hipparchus within a fraction of a second.

In Fig. 128 we have before us a *computational* tablet of great interest, being the oldest such tablet as yet discovered. It is of a class called by the Greeks *ephemerides*, meaning the daily predictions of an astronomical calendar. This particular *ephémeris* is therefore a page from a Babylonian astronomer's

almanac computed for the wear 425 B.C., the fortieth year of Artaxerxes I.

Each side of the tablet, obverse and reverse, is divided into two columns. In the *left-hand* column the astronomer has entered the monthly and lunar data: in the first line the length of the month, in the second the date of the full moon, and in the third the date of the moon's last visibility. There were thus three entries for each month. In the *right-hand* column a number of lines for each month predict the dates of the heliacal rising and setting of the planets and fixed stars. On the reverse, however, the column containing these predictions displays two additional predictions of the greatest interest. There are four entries for the month and they read as follows:

> On the first Mercury rises.
> On the third the Equinox.
> Night of the 15th, 40 minutes after sunset an eclipse of the moon begins.
> On the 28th occurs an eclipse of the sun. (Kugler.)

Kugler has calculated the dates of these two eclipses as having occurred on October 9 and 23, in —424 (astronomical), that is 425 B.C. The eclipse of the moon on the ninth of October was visible in Babylon; but that of the sun was visible only below the horizon of the city, and these ancient Babylonian astronomers who predicted it, were unable to see it. They evidently did not know beforehand that they would not be able to see it, and it should be noted that they were not in position to calculate the extent or place of visibility of a solar eclipse. It is thus doubtful whether they understood the nature of an eclipse. They were, however, able to compute the positions of the celestial bodies years in advance, especially those of the planets, giving dates and longitudes.

Of the instruments used in these observations, on which these remarkable calculations were based, we know nothing; but, however crude they were, it is quite evident that the Babylonians were the founders of astronomy and meteorology, and their amazingly industrious and discerning labors are not only of the highest interest in the history of civilization, but they are even of value to modern astronomy in the study of the moon.

It was into a world of researches and of astronomical knowledge such as we have suggested, that Greek travelers like Herodotus penetrated when they visited the east end of the Mediterranean, and especially if they went as far as Babylon itself. That the Greeks learned their astronomy in the beginning from the Babylonians there is no longer the slightest doubt. Even the name of the Babylonian observer and astronomer, from

FIG. 129. NINGIRSU, GOD OF THE OLD SUMERIAN CITY KINGDOM OF LAGASH IN LOWER BABYLONIA, CARRYING AWAY THE ENEMIES OF HIS CITY IN A NET WHICH IS SURMOUNTED BY THE LION-EAGLE EMBLEM OF THE CITY. The emblem is the same as that found also in Figs. 102 and 103.

whose work the Greeks drew, has in one case been identified. A cuneiform tablet of moon data signed by the Babylonian astronomer Kidinnu is the work of him whom Strabo quotes as *Kidénas* and Pliny as *Cidenas.*[30]

Next to science and religion and intimately involved in the latter, the most powerful influence from the Orient has been the ancient tradition of the state and the place of the ruler and the god in it. It is of especial interest to note this fact now at one of the greatest moments in the history of man, when the last surviving traces of the Oriental conception of the ruler and the state have suffered destruction.[31]

[30] Bezold, "Astronomie, Himmelsschau und Astrallehre bei den Babyloniern," *Sitzungsber. d. Heidelberger Akad. d. Wissensch., Phil.-hist. klasse*, 1911, 2. Abhandlung, p. 16, quoting from Schiaparelli; Cumont, "Florilegium de Vogué," pp. 159ff; and *Neue Jahrb. f. d. klass. Alt.*, 1911, XXVII., p. 8; and Kugler, BB. 122. A large mass of quotations from the cuneiform originals has been identified by Bezold and Boll in the astrological treatises of the Greeks (*Sitzungsber. der Heidelberger Akad. d. Wiss., Phil.-histor. Klasse*, 1911, 7. Abhandl.: *Reflexe astrologischer Keilinschriften bei griechischen Schriftstellern*).

[31] The following paragraphs to the end are adapted from the author's

On one of the early Sumerian monuments of Babylonia (Fig. 129), we see the god of the Sumerian city-kingdom of Lagash bearing in his mighty grasp the heraldic symbol of the state, surmounted by the eagle which was yet to cross lands and seas to become the American eagle: yonder the symbol of an Oriental autocracy, here that of a liberty-loving Western democracy. This scene, in the transparent symbolism of the Orient, epitomizes the early Oriental polity, picturing to us the victorious state upheld in the guiding and protecting hand of the god who was its head. Now this is of course a purely ideal scene—one that never existed except in sculpture.

It was possible, however, to express the same relationship between the god and the state in an actual scene, by employing a symbol of the god instead of a symbol of the state, and by putting this symbol of the god into the hands of a human representative of the state. By so doing the Oriental believed without qualification that he was thus introducing the potent presence of the god into earthly scenes and making him effective in earthly crises. In sculptured representations of the battle array, we find the Egyptians mounting a symbol of their god Amon in a chariot and driving with it into the midst of the fray (Fig.

FIG. 130. SYMBOL OF THE GREAT GOD OF THE EGYPTIAN EMPIRE AMON MOUNTED IN A CHARIOT READY TO BE CARRIED INTO BATTLE LIKE A MODERN FLAG.

discussion: "The Eastern Mediterranean and Early Civilization in Europe," Annual Report, Am. Hist. Assn., 1914, pp. 103ff.

FIG. 131. SYMBOL OF THE GREAT GOD OF THE ASSYRIAN EMPIRE ASSUR MOUNTED IN A CHARIOT AND CARRIED INTO BATTLE LIKE A MODERN FLAG.

130), believing that the god was thus actually present and assisting in the conflict. We recall the similar use of the sacred ark of the Hebrews, which they sent into battle against the Philistines. The Assyrian sculptures exhibit the same custom (Fig. 131). When in camp the Assyrians housed their battle symbols of the god in a tent shrine, where the chariot bearing them stands in one corner, and priests minister to them as to the god of the state whose visible presence makes victory certain (Fig. 132). Such a custom was purely Oriental. The eagle standard of Jupiter Optimus borne at the head of the Roman legion can hardly have had any other origin.

Similarly we remember how Constantine later, thinking to honor the newly triumphant Christian faith, made a battle standard bearing a symbol of the Christ at the top, and this standard led the troops into battle. He too had a portable tent shrine for this standard, with daily ministrants attending upon it. Was it merely an accident that that Emperor who in the present war thought to possess Constantine's city and conquer the East in whose lore he was steeped—was it merely an accident that this Emperor continually reminded his troops that the power of divinity went with them in every battle?

This visible leadership of the god in the crisis of battle in the ancient Orient, was but one function in his guidance of the Oriental state. For the god was the source of the king's legal authority as the head of the state, and I know of no monument of the early East which so forcibly pictures this concept of the state as the sculpture surmounting the shaft which bears the

laws of Hammurapi (Fig. 133). In this noble relief scene the Babylonian king at the left is depicted receiving from the god enthroned at the right the great code of laws which is engraved in thirty-six hundred lines around the shaft supporting this relief. The king thus receiving the law from the god enters into an intimate coalition, which makes the sovereign the infallible representative of the god, a representative whom no mortal would venture to challenge.

We have here a state which is a divine institution administered by a ruler who is the recognized agent of divinity. Of the Holy Roman Empire, in his volume on that subject, Lord Bryce remarks: "in order to make clear out of what elements the imperial system was formed we might be required . . . to travel back to that Jewish theocratic polity, whose influence on the minds of the medieval priesthood was necessarily so profound" (3d ed., p. 3). Had this distinguished historian's studies carried him back into the remoter reaches of the ancient Orient he would of course have recognized at once that what he calls "Jewish theocratic polity" was in fact only a very late manifestation of a conception of the state already wide-spread in the early East thousands of years before the Hebrew theocratic monarchy arose.

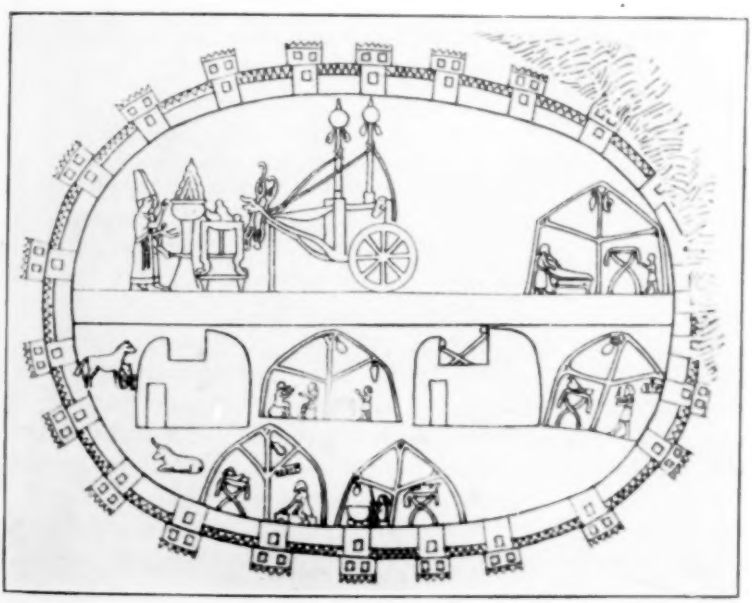


FIG. 132. FIELD SHRINE OF THE PORTABLE BATTLE EMBLEM OF ASSUR, WITH PRIESTS MINISTERING BEFORE IT AS TO THE GOD HIMSELF.

FIG. 133. HAMMURAPI THE GREAT KING OF BABYLONIA RECEIVING THE LAW FROM THE SUN-GOD. (21st century B.C.) The king is at the left shrouded in a long garment. The god at the right is enthroned on a mount as suggested by the stones under his throne. The flame emblems rising from his shoulders show his character as a solar deity. The relief surmounts the shaft which bears his great code (Fig. 108).

Men who believed in such a state accepted absolute monarchy as a matter of course, and never raised the question or entered upon a discussion of the proper form of state. We can not here follow the course of this conception of the state as along with many other elements of the great fabric of Oriental civilization it entered Europe in the train of Alexander's conquests and, passing through the Oriental despotism of the Byzantine emperors, infected all Europe with the doctrine of the divine right of kings. In the person of the ablest and the most guilty of the fallen European sovereigns, a ruler who persistently proclaimed his belief in his own divine right—in the person of this ruler we of this generation have been watching the final and complete destruction of an ancient Oriental concept of the state and the sovereign.

But this hoary Oriental concept of the state, although much modified by democratic tendencies, did not stop on the other

side of the Atlantic. Its influence was still felt in the New England town-meeting, which was as much a meeting of the church as it was of the town; and our pilgrim forefathers little dreamed that in the distant vista behind the venerable figure of Moses dominating their assemblies, there loomed the remote and colossal shadows of Cheops and of Hammurapi.

The reader will have discerned that the culture forces issuing from the birth-lands of civilization, which we have termed the Egypto-Babylonian group, have continued their profound influence on Western life, even down into our own day —a fact which is especially evident in the great historical religions, Judaism and Christianity. The particular purpose of these lectures, however, has been to reach much further back than is done by the historian, and in so far as such a slender sketch would permit, to marshal some of the more graphic and outstanding evidences which permit us to trace the rising life of man from the cave hunters of France and Spain in the Paleolithic Age, some ten or twelve thousand years ago, to the emergence of great civilized societies in the Near Orient, and the transmission of civilization from such communities to the shores of Europe beginning five thousand years ago. Even before the civilization of the Near East had been made possible by the development of writing and metallurgy, Europe had received cattle and grain from the Orient, as indispensable preliminaries to civilization (Fig. 134, first bracket). After the *first* transition of civilization from the Nile valley to southeastern Europe (Fig. 134, second bracket), the destructive invasion of the early Greek barbarians crushed the earliest civilization of Europe so that not even writing survived. The development of the Greeks was therefore accompanied by a *second* transition of civilization from the Orient to Europe, this time

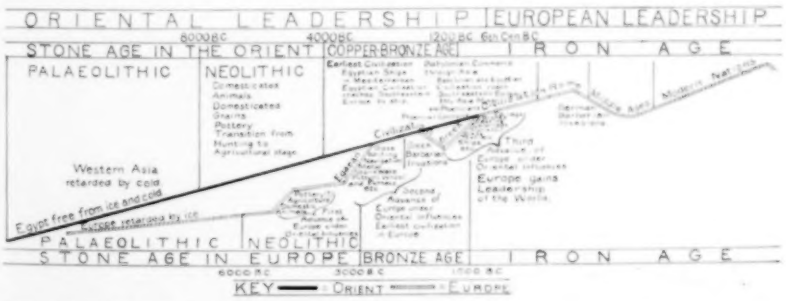


FIG. 134. DIAGRAM VISUALIZING THE RISE OF CIVILIZATION IN THE ORIENT AND ITS TRANSITION THENCE TO EUROPE.

from the entire Egypto-Babylonian group (Fig. 134, third bracket). But Hellenic genius never permitted the Greeks to remain merely passive recipients of culture from without. Building on foundations largely Oriental, they erected a splendid structure of civilization which nobly expressed their marvelous gifts, and brought them an unchallenged supremacy which was already evident in the sixth century B.C. The leadership in civilization then passed finally and definitely from the Orient to Greece. In recognizing this fact we have reached the culmination of that vast synthesis which we are the first generation of men to be able to make—a synthesis which enables us to trace the developing life of man from a creature but little superior to the simians, through unnumbered ages of struggle and advance, leading us from the cave savages of southern France through the conquest of civilization in the Orient, its transition to Europe, and thus through the supreme achievements of Greek genius, to the highly developed life of man at the present day.

THE MECHANISM OF EVOLUTION

IN THE LIGHT OF HEREDITY AND DEVELOPMENT

By EDWIN GRANT CONKLIN

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V. The Cellular Basis of Ontogeny and Phylogeny

A. GERM CELLS AND SOMATIC CELLS

1. *Germ Cells the only Living Bond between Generations and Species*

IMAGINE the amazement and incredulity of the naturalists of a former generation, who thought of evolution only as the transformation of developed organisms under the influence of changing environment, if they could learn that to-day the greatest problems of ontogeny and phylogeny center in the structures and functions of the germ cells! And yet this is strictly and literally true. The germ cells form the only living bond not only between generations but also between species. The germ cells contain the physical basis not only of heredity but also of evolution. We know little about the changes taking place in germ cells which cause evolution, we are at present unable to initiate and control such changes, but at least we know where to look for them. The mechanism of evolution is at present largely unknown, but at least we know where that mechanism is located.

2. *Germ Cells and Somatic Cells are Fundamentally Alike*

When once the fact of the importance of the germ cells in ontogeny and phylogeny was appreciated there arose a belief that these cells must be essentially different from all other kinds of cells. Germ cells were contrasted with somatic cells and it was supposed that there must be a world-wide difference between cells which could give rise to new individuals or new species and those which constituted the various tissues of the body. And yet in many respects these cells are very similar. Both have a nucleus and a cell-body; in both the nucleus contains chromosomes that are usually of the same number, shape and relative size in all cells of a given species and while the cell-body of somatic cells undergoes marked differentiations in the various

tissues these differentiations are probably no greater than the corresponding differentiations in the germ cells. Indeed the differentiations of a mature spermatozoon are probably as great as those of any muscle cell or nerve cell and the differentiations of the egg are as marked as those of any gland cell, while the differences between the male and female germ cells are quite as great as the differences between a muscle cell and a nerve cell. Furthermore there are many evidences that up to a certain stage of development cells may differentiate in one direction or another depending upon environmental conditions. Many cells which under certain conditions would have formed tissue cells may under other conditions form germ cells and *vice versa*, and this is especially true among lower organisms where cell differentiations appear more slowly and do not go so far as among higher forms. Such changes in the fate of a cell can not take place after differentiations have passed a certain stage; fully developed muscle cells or nerve cells can not become germ cells, nor can fully developed germ cells become tissue cells except by the process of embryonic development; but this means only that there is a critical stage in development beyond which differentiation is not a reversible process. All kinds of tissue cells as well as germ cells develop out of germ cells and it is evident that there is no *fundamental* distinction between the two.

3. *Nucleus (Germplasm) and Cytoplasm (Somatoplasm) are Fundamentally Different*

But while there is no fundamental difference between germ cells and somatic cells there is in every cell, excepting perhaps the very simplest organisms such as bacteria, a fundamental difference between nucleus and cytoplasm. Chemically and physically, morphologically and physiologically these two constituents of all cells are sharply distinguished. First of all there is a marked chemical difference between the two; the nucleus is acid in reaction, the cytoplasm alkaline; the nucleus contains a relatively large amount of phosphorus, the cytoplasm almost none at all; many compounds, especially nucleinic acid and nucleo-proteins are found exclusively in the nucleus. The nucleus is usually more dense and more highly refractive than the plasma.

But it is in morphological and physiological characteristics that the differences between nucleus and plasma reach a climax. The peculiarities of nuclear membrane and linin framework, of nuclear sap and chromatic granules, of chromosomes and

nucleoli are too well known to need emphasis. And when to these morphological peculiarities of the nucleus are added its physiological characteristics,—its indispensability in constructive metabolism, regulation and regeneration, its control over cell-differentiation and development, its peculiarities of division, its unfailing continuity from cell to cell and from generation to generation,—it will be seen that this contrast between nucleus and plasma is fundamental. Although germ cells and somatic cells are not essentially unlike, nucleoplasm and cytoplasm are, and there is abundant evidence that germplasm is located in the nucleus, somatoplasm in the cell-body.

4. *Cell Division*

From every point of view our knowledge of organisms has been greatly advanced by the prolonged and extensive study which has been devoted to cell division. The older views as to the origin of cells by "free formation" or *de novo* have been referred to in a previous section (p. 489) and these false views have been responsible for many erroneous theories of heredity and evolution which persist in one form or another to this day. On the other hand the doctrine of Remak (1841) that every cell comes from a preexisting cell by a process of division has been found to be universally true and has greatly influenced almost all lines of biological research.

It was at first supposed that both the cell-body and the nucleus always divided by a process of simple constriction; afterwards it was discovered that the nucleus usually divides in a much more complicated manner and although it is still generally held that the cell-body divides by simple constriction there are evidences that this also is much more complicated than has commonly been supposed.

Neither the nucleus nor the cell-body is a simple, homogeneous structure which may divide equally by simple mass constriction. The nucleus is really a compound structure composed of a larger or smaller number of karyomeres or nuclear units, while the cell-body contains many different structures; a simple mass constriction of the entire cell could not possibly divide all of these equally. Accurate division of a complex cell requires a special mechanism and this is found in *mitosis* or *karyokinesis*.

(*a*) *Mitosis or Indirect Nuclear Division.*—During stages of division there appears in the nucleus a number of deeply staining threads or rods, the chromosomes, while other threads which do not stain readily form a spindle-shaped figure. In most

animals and in many of the lower plants there is in the cytoplasm opposite each pole of the spindle a star-shaped figure, the *aster*, with a minute body, the *centrosome*, at its center. The nuclear membrane then dissolves and its contents are set free into the cell body; in place of the nucleus there is left a spindle with the chromosomes gathered around its equator and with the centrosomes and asters at its two poles. Then each chromosome splits lengthwise into two daughter chromosomes and these halves move in opposite directions along the spindle toward its poles, where they unite to form the two daughter nuclei.

This process is known as *mitosis* or indirect nuclear division and its chief significance is found in the fact that each chromosome is divided into daughter chromosomes each of which is identically like the other.

In the meantime complicated movements are taking place in the cell-body outside of the nucleus, which move the mitotic spindle into a definite position in the cell, sort and localize various constituents of the cytoplasm and finally lead to the division of the latter in a plane passing through the equator of the spindle, thus completing the division into two cells.

(*b*) *Persistent Identity of Chromosomes.*—Although the chromosomes constitute so striking a part of a dividing nucleus they usually disappear entirely after division and in their stead one finds only a single nuclear vesicle containing a clear, non-staining fluid or gel, the *achromatin*, imbedded in which are the granules or threads of *chromatin*. Usually no trace of chromosomes can be seen in such a "resting" nucleus.

However the fact that the same number of chromosomes is usually found in every dividing nucleus of any given species, that these chromosomes split lengthwise into daughter chromosomes which then unite to form the daughter nuclei, and that at the next division the same number of chromosomes, having the same shapes and relative sizes, come out of a nucleus as went into it at the preceding mitosis,—these facts early gave rise to the hypothesis that in some way or other the chromosomes preserve their individuality or identity throughout the "resting" stage between successive divisions.

This hypothesis of the "individuality of the chromosomes" has now been verified in a number of cases by actually tracing certain chromosomes into the daughter nucleus and through the "resting" stage until they emerge at the next division as typical chromosomes. It is found that each chromosome absorbs fluid from the cytoplasm and swells up to form a chromosomal

vesicle (Fig. 11). These vesicles then unite to form the daughter nucleus and usually the partition walls between vesicles disappear leaving what appears to be a single nuclear vesicle, but in certain favorable objects it can be seen that each chromosomal vesicle persists through the whole of the resting stage and at the next mitosis the chromatin granules within each chromosomal vesicle are drawn together into a chromosome which is in all respects similiar to the one from which that vesicle arose. Probably every chromosome exists as a chromosomal vesicle

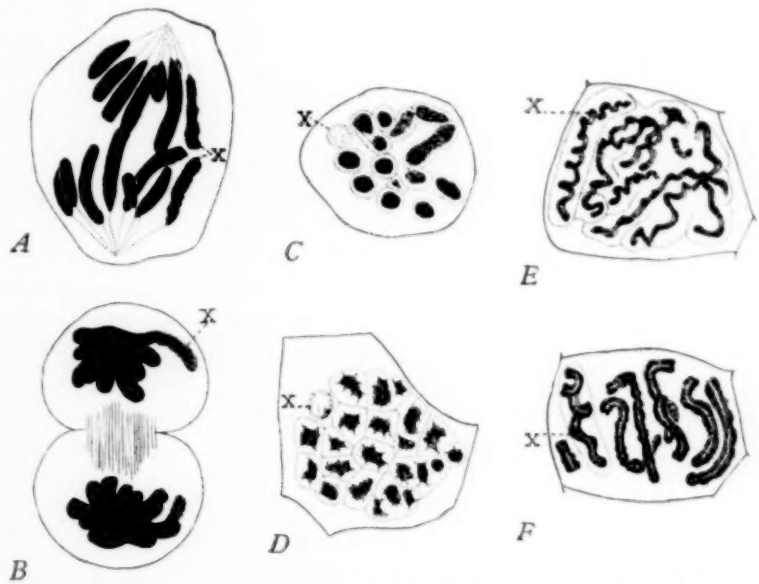

FIG. 11. SPERMATOGONIA OF *Phrynotettix*. *A* and *B*, Middle (metaphase) and late (anaphase) stages of mitosis showing separation of daughter chromosomes, among them the *X* (sex) chromosomes. *C* and *D*, Last stages (telophase) of mitosis passing into the resting nucleus; each chromosome is swelling up into a chromosomal vesicle. *E* and *F*, Early stages (prophase) of next division, showing the reappearence of a chromosome in each vesicle and in *F* the longitudinal splitting of every chromosome. (After Wenrich.)

during the resting stage and as a condensed chromosome during division and thus persists from cell to cell and from generation to generation. Possibly other parts of a cell may preserve indefinitely their individuality or identity, but in the case of the chromosomes this is no longer a mere hypothesis but an established fact.

A chromosome, like any living organism, undergoes many changes in its life cycle without losing its identity. The changes in form and staining reaction which it undergoes in passing from the resting to the dividing stage and *vice versa* indicate

that persistent identity does not imply fixity of its entire organization. Nevertheless something, some part of that organization, must persist through all the changes of the division cycle, and it is evident that this is not the deeply-staining portion of the dividing chromosome for in the resting stage this chromatic material may lose its affinity for dyes and coincidently the nucleolus (karyosome) become chromatic, while these changes are reversed at the beginning of mitosis. Likewise in dessicated cells Hickernell found that the chromatic material

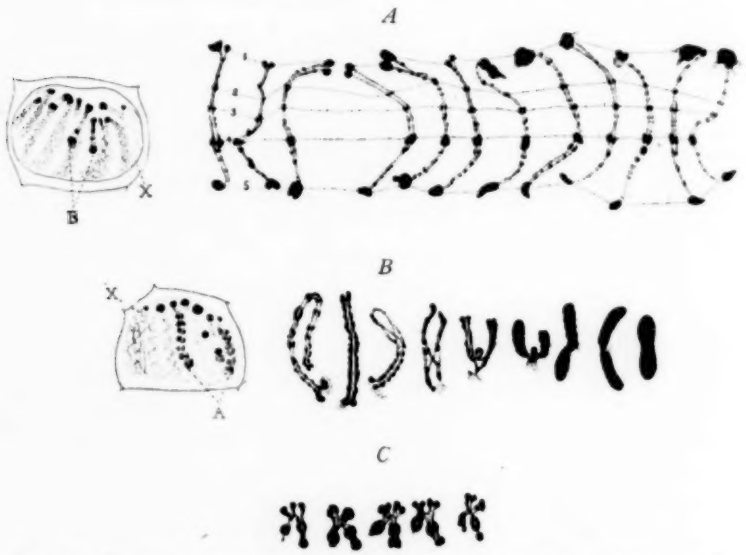

FIG. 12. SYNAPSIS (CONJUGATION) OF CHROMOSOMES IN *Phrynotettix*. *A*, Resting nucleus at left shows indistinct chromosomes, among them chromosome *X* and the pair *B*. At the right are 12 pairs of *B* chromosomes, each from a different animal, showing side by side conjugation of chromosomes of a pair and homologous chromomeres (1, 2, 3, 4) in each pair. *B*, Similar stages in chromosome pair *A*. Some of the chromosome pairs at the right show a secondary longitudinal split and a "crossing-over" of the halves. *C*, Tetrads (bivalent chromosomes) of chromosome pair *B*, formed by shortening and thickening of the chromosome pairs and by the appearance of the secondary split. (After Wenrich.)

moves to the periphery of the nucleus whereas in cells recovering from dessication it goes back into the nucleus. Consequently it seems probable that the persistent part of a chromosome is the achromatic framework or linin in which chromatin is present at certain phases of the cell cycle and absent at others, just as the persistent part of a red corpuscle is the cytoplasmic framework which may or may not contain hæmoglobin.

There is evidence that the chromosomes themselves are compound structures and that just as nuclei are composed of

chromosomes or their vesicles, so the latter are composed of smaller units, the chromatin granules or chromomeres. In the formation of chromosomes, the chromomeres appear like beads on a string and in the splitting of chromosomes each chromomere divides into equal halves, and just as the chromosomes are specific bodies each of which preserves its identity, so each chromomere is probably a specific and persistent body. Wenrich has shown that in certain chromosomes of a grasshopper there are specific chromomeres occupying particular positions and that some of these chromomeres preserve their identity throughout the resting stages and are therefore persistent structures (Fig. 12). In all probability further work will demonstrate that every chromomere in a chromosome is a specific and persistent body. Indeed it is probable that chromomeres are much more constant than chromosomes. McClung and his pupils have shown that the number of chromosomes in a given species or in related species may not always be constant, owing to the fact that certain chromosomes may fragment while in other cases separate ones may unite. But whatever the number of chromosomes may be there is apparently a constant number of chromomeres in every species, perhaps even in all closely allied species, and variations in the number of chromosomes are due to the grouping of the chromomeres into a larger or smaller number of chromosomes.

5. *Panmerism*

It is one of the characteristics of organisms and parts of organisms that they are capable of assimilation, growth and division. This is true not only of the larger units of organization but probably also of every unit down to the ultra-microscopic parts of cells and protoplasm. Indeed the larger and more complex units may lose this property while it is still retained by the smaller units. Entire organisms and organs may lose the power of continued growth and division while it is still retained by cells or parts of cells. By this process of growth and division every cell comes from a preceding cell, every nucleus from a nucleus, every chromosome from a chromosome, every chromomere from a chromomere, every gene from a gene, —and in general every vital unit from a preceding unit of the same kind. So far as is known the simpler units always divide equally both in size and quality; this is true of the units composing the nucleus such as chromosomes, chromomeres, genes and probably also of the individual units of the cytoplasm.

But entire cells or groups of cells may divide equally or unequally and the differentiations of development are due mainly to this fact. Such differential divisions of cells are due in the main to different combinations and localizations of units which divide equally and non-differentially, and *in general all forms of differentiation, variation, and evolution are due to different combinations of vital units, whether they be organs, tissues, cells, plastids, chromosomes, chromomeres, genes or subgenes;* just as all forms of chemical compounds are due to different combinations of some 80 chemical elements, and all words, sentences, languages and literatures are the result of different combinations of a small number of letters. However the smaller units of living organization grow and divide equally and not differentially and this property perpetuates the identity of particular kinds of units.

But it is not necessary to assume that everything capable of increasing its own substance is alive. Certainly many substances which are not protoplasm have this power. Ferments which are capable of self-propagation, or substances which produce ferments which in turn are capable of producing those substances, are known. Such reactions are called auto-catalytic and it is probable that many phenomena of reproduction, especially among the smaller units of organisms, are autocatalytic reactions. We do not know whether in such reactions colloidal particles, or molecular aggregates, grow and divide, but this is just what takes place in the parts of cells which are visible with the microscope. These parts of cells are not alive in the sense or to the same extent that the entire cell is; they are incapable of continued independent existence, and it is probably as erroneous to hold that every minute unit of organization is composed of living protoplasm as it would be to regard every brick in a building as a minute house.

B. MECHANISM OF HEREDITY

The mechanism of heredity is to be found in the structure and functions of the germ cells, for everything that is transmitted from one generation to the next must be through the germ cells. The method of studying this mechanism must be by the correlation of particular features of the germ cells with particular phenomena of heredity, in short by the cooperation of cytology and genetics.

1. *Chromosomes and Inheritance Units*

It was pointed out on a previous page that there are many reasons for supposing that the germplasm is located in the nucleus, the somatoplasm in the cell body. Furthermore the chromosomes more nearly fulfill the requirements of an inheritance material than any other constituents of the nucleus. The evidence that the Mendelian factors or genes are located in the chromosomes may be summarized as follows:

(*a*) *General Equivalence of Germplasm and of Chromosomes in Egg and Sperm.*—A study of heredity shows that on the whole offspring inherit as much from one parent as from the other and therefore as many genes must be derived from the sperm as from the egg. But the only substances which are known to come in approximately equal quantities from the two sex cells are the chromosomes. The egg at the time of fertilization contains a relatively large quantity of cytoplasm, yolk and other substances in the cell-body. The spermatozoon, on the other hand, is one of the smallest of all cells and usually its head only enters the egg, leaving the tail and most of the cytoplasm outside. The head of the spermatozoon consists almost entirely of a condensed nucleus in which is the characteristic number of chromosomes. In the egg nucleus also this characteristic number of chromosomes is present. The egg and sperm nuclei come together within the egg and their chromosomes mingle but do not fuse together nor lose their identity. The chromosomes which come from the egg and those from the sperm are not only equal in number and size but are also alike in shape so that in every fertilized egg there are two sets of similar chromosomes, one set from the egg and the other from the sperm. The chromosomes are the only portions of the male and female germ cells which are approximately equal in volume and it is therefore probable that they are the seat of the inheritance material.

(*b*) *Equal Distribution to all Cells.*—Since inherited characters of one or the other parent may appear in every part of the bodies of offspring, it must be that inheritance units from the two parents are distributed equally to every cell. So far as known the only portions of the egg and sperm which are distributed equally to every cell of the developing organism are the chromosomes. At the first division of the fertilized egg and at every subsequent division each chromosome divides equally and its halves go into the two daughter cells. Therefore every cleavage cell, and ultimately every cell of the adult body comes to contain one full set of chromosomes from the egg and another

set from the sperm. Since the chromosomes are the only portions of the egg and sperm which are known to be distributed equally to every cell, it is probable that they contain the inheritance factors.

(*c*) *Conjugation and Reduction of Maternal and Paternal Chromosomes.*—In the last stages of the formation of the germ

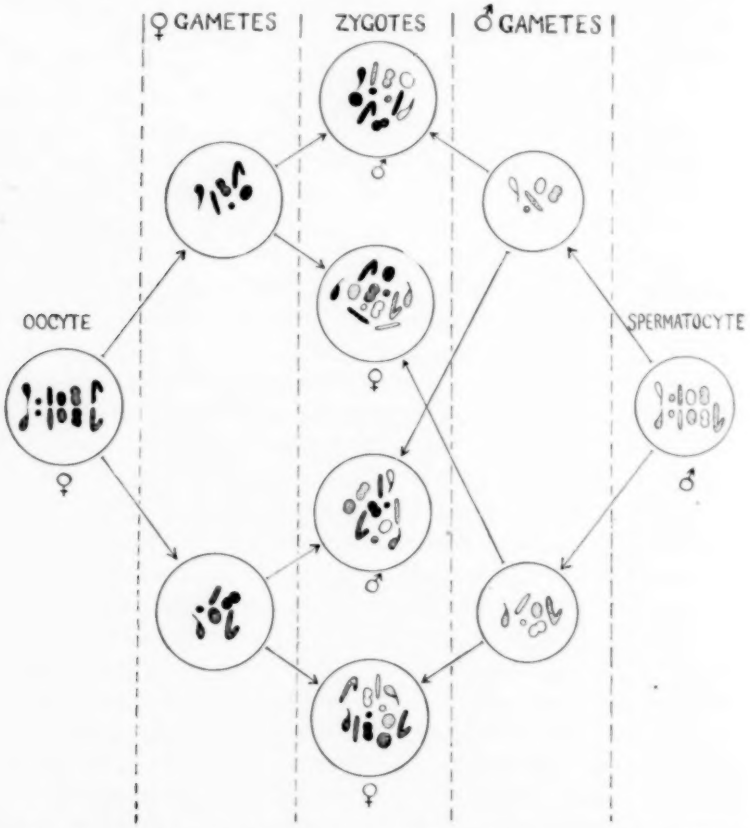

FIG. 13. DIAGRAM SHOWING SOME OF THE POSSIBLE DISTRIBUTIONS OF CHROMOSOMES OF GRANDPARENTS TO GRANDCHILDREN. Chromosomes of paternal grandfather unshaded, of paternal grandmother stippled, of maternal grandfather with cross lines, of maternal grandmother black. The sex chromosomes are *J*-shaped, a pair being present in the female and a single one in the male. In the oocyte and spermatocyte synaptic pairs of homologous chromosomes are shown separating so that the gametes contain only one of each pair. By the union of gametes to form zygotes the double number is restored.

cells the two sets of parental chromosomes temporarily unite, and in general long chromosomes pair with long ones, short ones with short ones and those of peculiar shape with others of similar shape; in short the members of each pair are homologous

chromosomes. This process is known as *synapsis* or the conjugation of the chromosomes, the pairs are called synaptic pairs or bivalent chromosomes; and in some cases it can be demonstrated that one member of each pair comes from the father, the other from the mother (Figs. 12, 13, 15, 16).

In all ordinary divisions every chromosome splits into two and the halves go into the daughter cells, but in one or the other of the last two divisions leading to the formation of the germ cells, the synaptic pairs separate, whole chromosomes going into the daughter cells. By the separation of whole chromosomes in this division the germ cells come to contain only one half as many chromosomes as the other cells of the body. The full number of chromosomes is the diploid number ($2n$), the reduced number the haploid ($1n$) and the division by which this reduction is effected is known as the "reduction division." On the other hand ordinary divisions, in which each chromosome splits and the daughter cells contain as many chromosomes as the mother cell, are known as "equation divisions."

Since one chromosome of each synaptic pair is from the father and the other from the mother and since these chromosomes separate freely in the reduction division, that is each member is free to move to either pole of the mitotic spindle, it follows that each germ cell or gamete contains one full set of chromosomes, some of which are from the father and others from the mother, but only one chromosome of each pair is found in any gamete (Fig. 13).

The correlation between these cytological facts and the phenomena of heredity are very striking. All hybrids carry two sets of factors, derived from the two parents, but in the formation of the gametes these factors separate so that every germ cell is pure with respect to any character. In this respect the factors, which are invisible, behave exactly as do the chromosomes which are easily seen. Indeed it would be impossible to invent a more perfect mechanism for the segregation of Mendelian factors than is found in the union of maternal and paternal chromosomes into synaptic pairs and their subsequent separation in the reduction division. This complete parallelism between the behavior of the chromosomes and of the inheritance factors is convincing evidence that the factors are located in the chromosomes (Figs. 14, 15).

(*d*) *Doubling of Chromosomes and of Factors in Fertilization.*—Finally in the union of male and female gametes, each having the reduced or haploid number of chromosomes, the

somatic or diploid number is restored. The chance combination of chromosomes in fertilization is identically like the chance combinations of inheritance factors, and both yield the same Mendelian ratios. Mendelian segregation and recombination of factors is exactly parallel to the reduction of chromosomes in gametogenesis and their union in fertilization. In every respect chromosomes may stand as the visible symbols of factors (Figs. 14, 15). It is highly probable therefore that the factors are located in the chromosomes.

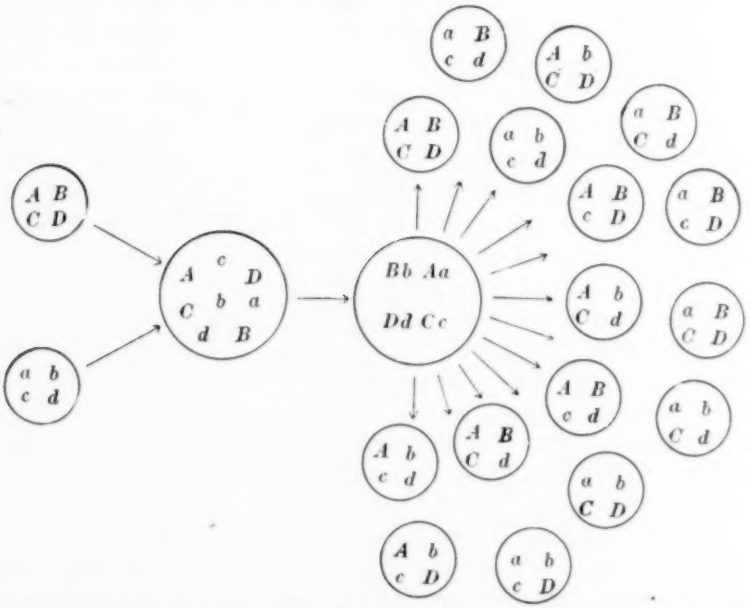

FIG. 14. DIAGRAM SHOWING UNION IN FERTILIZATION, CONJUGATION IN SYNAPSIS AND SEGREGATION IN FORMATION OF GAMETES of Factors *A*, *B*, *C*, *D* of the egg and *a*, *b*, *c*, *d*, of the sperm. (After Wilson.)

(*e*) *Sex-Determination and "Sex-Chromosomes."*—Still further evidence that the chromosomes are the seat of inheritance factors is found in the relation of some of these bodies to sex-determination.

The cause of sex has been a subject of speculation and theorizing for hundreds if not thousands of years, but within the last fifteen years it has been discovered that at least the initial cause of the differentiation of the two sexes is inherited, although there may be many other causes which are environmental. In this respect sex does not differ from any other inherited character; many causes both hereditary and environ-

mental are involved in the *development* of any inherited character; all that is implied in saying that any character is *inherited* is that its initial differential is transmitted through the germ cells.

In this sense it is known that in many animals and plants sex is inherited as a Mendelian character, one sex being homozygous and the other heterozygous for this character and that consequently the heterozygous sex forms two sorts of germ cells, the homozygous but one and the chance combination of

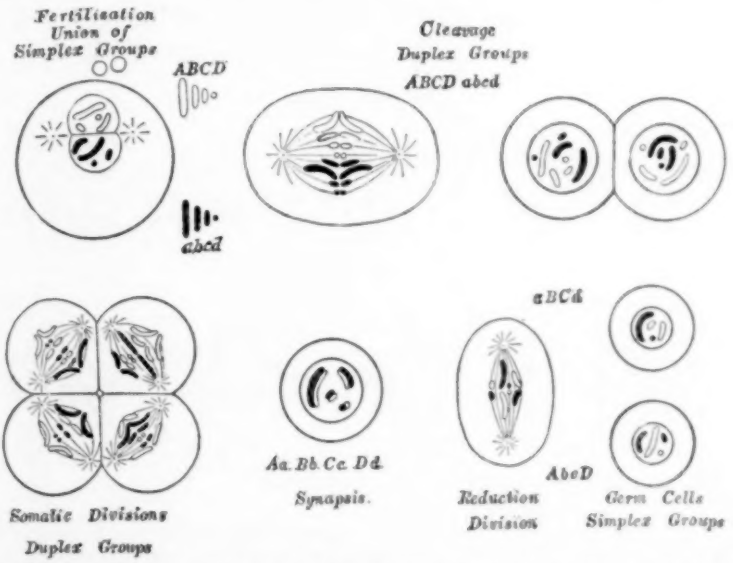

FIG. 15. DIAGRAM OF UNION OF CHROMOSOMES OF EGG AND SPERM IN FERTILIZATION, THEIR CONJUGATION IN SYNAPSIS AND SEGREGATION IN FORMATION OF GERM CELLS, corresponding to the factors shown in Fig. 14. (After Wilson.)

these germ cells yields equal numbers of homozygotes and heterozygotes, which fact explains the numerical equality of the two sexes.

In all such instances we have a plain Mendelian case of the crossing of a heterozygous with a homozygous form in which one half of the offspring are homozygous and the other half heterozygous, as shown in the following scheme:

Female (homozygous) produces Eggs of one type..... = ♀

Male (heterozygous) produces Sperms of two types..... = ♀ ♂

All possible crosses result in..... = 2♀♀ : 2(♀)♂

or the ratio of males to females is 1 : 1.

In the spermatogenesis of certain insects it had been observed that there was an odd number of chromosomes and in synapsis when homologous maternal and paternal chromosomes unite in pairs one of these chromosomes was left without a mate; it was therefore called the "odd" or "accessory" chromosome. In the reduction division when the two chromosomes of a pair separate the odd chromosome went entire to one pole of the mitotic figure and there was no corresponding chromosome at the other pole; consequently, one of the two gametes formed by this division had one chromosome more than the other and two types of spermatozoa were formed in equal numbers,—one type with and one without the "odd" chromosome (Fig. 16).

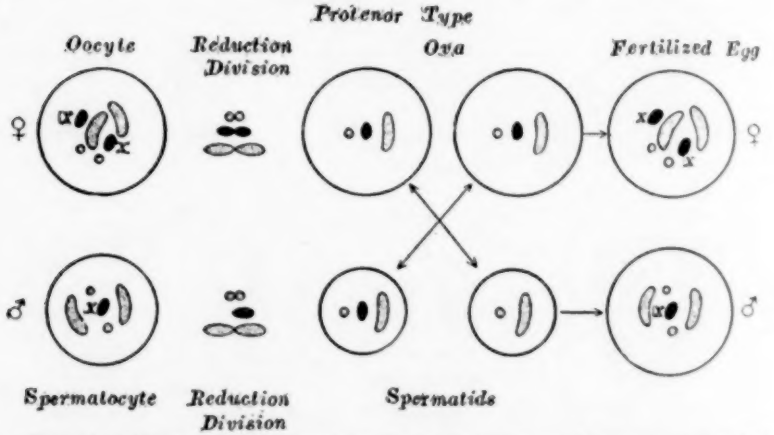

FIG. 16. DIAGRAM OF CHROMOSOMAL DETERMINATION OF SEX IN *Protenor* (*XO* TYPE). The oocyte contains 6 chromosomes, 2 of them being sex chromosomes (*X*), the spermatocyte contains 5, there being only 1 *X*; after reduction each egg contains 1 *X* and 2 ordinary chromosomes; half of the spermatozoa contain 1 *X* and the other half lack it; if an egg is fertilized by a sperm with an *X* a female results, if by one without the *X* a male is produced. (After Wilson.)

Since the 1:1 ratio of these two types of spermatozoa corresponds to the usual sex ratio, McClung suggested that this "odd" chromosome was a sex determinant. Wilson and Stevens then found that all eggs contain this "odd" chromosome, which was therefore called the "sex" chromosome, or the "*X*" chromosome, and that any egg fertilized by a sperm containing this chromosome produced a female, whereas if fertilized by a sperm without it a male was produced, as is shown in the following diagram:

Chromosomal Constitution of Male (♂) Zygote *XO*, of Gametes. X O

of Female (♀) " *XX*, " " . X X

All posible combinations of these Gametes (indicated by arrows) 2XX(♀):2XO(♂)

Later Wilson and Stevens discovered that in the males of certain other insects the "odd" chromosome had a mate which was small or rudimentary and which they called the "*Y*" chromosome. Consequently the sex chromosomes of the male were in these cases *X* and *Y*, while those of the female were *X* and *X* and the chance combinations of the gametes formed by these animals yielded equal numbers of the combination *XY* (♂) and *XX* (♀) (Fig. 17).

At present it is known in more than one hundred species of animals and plants that with respect to the sex chromosomes two types of spermatozoa occur and but one type of ova, that

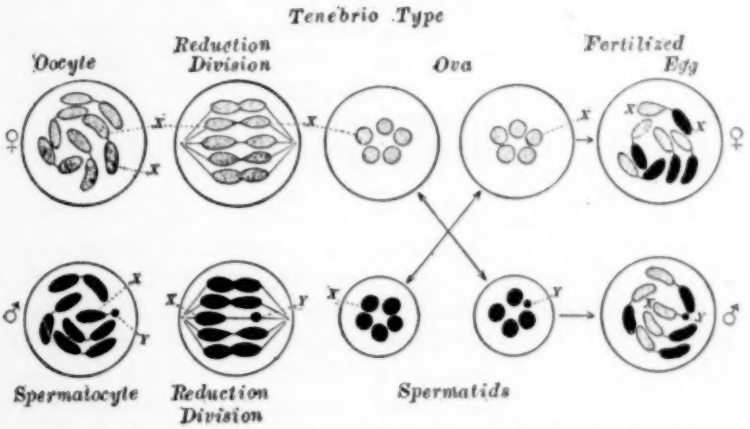

FIG. 17. DIAGRAM OF CHROMOSOMAL DETERMINATION OF SEX IN *Tenebrio* (*XY* TYPE), showing 5 synaptic pairs of chromosomes (there are actually 10 pairs). In the oocyte the sex chromosomes (*XX*) are equal in size and after reduction each ovum contains 1 *X*; in the spermatocyte these chromosomes are unequal (*XY*) and after reduction half of the spermatozoa contain a large *X* and half a small *Y*; sex is determined by the chance union of one or the other of these types of spermatozoa with the single type of ova.

eggs fertilized by one type of sperm produce males and by the other type females. In a few cases among Lepidoptera and birds there is evidence that the female is heterozygous for sex, the male homozygous, and that correspondingly two types of ova are produced and but one type of spermatozoa; but this does not affect the general principle that sex is determined by the chance union of gametes bearing particular sex chromosomes.

This correlation between the presence or absence of a whole chromosome and of a developed character such as sex, is the only case of the kind that is known and more than anything else it has served to prove that the chromosomes contain the Men-

delian factors. The absence of a whole chromosome is plainly visible under the microscope, whereas the absence of a single factor or gene from a chromosome would never have been seen. These fortunate cases in which the male lacks a whole chromosome give ocular proof of the chromosomal theory of heredity.

Environmental Influences.—It should be said that a number of apparent exceptions to the chromosomal determination of sex are known. In some of these cases environmental conditions change the usual 1:1 sex ratio or lead to the development of "intersexes" which are more or less intermediate between males and females. Departures from the normal sex ratio are sometimes due to the early death of one type of gametes or zygotes; "intersexes" may be caused by a balancing of male-producing and female-producing factors in the zygote, or of conflicting genetic and environmental factors in development. These cases illustrate the necessity of distinguishing between the hereditary determination of sex and its ontogenetic development.

Probably in every case these apparent exceptions to the chromosomal determination of sex may be explained in conformity with that theory; in any event this theory is now so well established in so many different cases that it may be accepted as the usual if not the only method of sex determination. But this means only that the initial factors for sex *determination* are carried in a particular chromosome. Doubtless there are many other factors in the *development* of sex, some of which are germinal and others environmental.

The male or female condition may be regarded, therefore, as the result of the dominance of male-determining or female-determining factors, and the condition of "intersexes" as the result of the partial dominance of one or both of these factors. This applies of course to the primary sex characters, such as ovaries and testes, and also to secondary characters which are associated with one or the other sex, such as peculiarities of size, color, hair or feathers, mammary glands, voice, instincts and habits, etc. The full development of these secondary sex characters is usually limited to one sex or the other; they are known as *sex-limited* characters and their development is dependent upon the dominance of the male-determining or the female-determining factors, whether those factors be hereditary or environmental.

Sex-linked Characters.—Another class of characters which Morgan has called *sex-linked* are inherited in the same way that sex itself is and for the reason, as he has proved, that their

genes are located in the sex-determining chromosome. These characters may have nothing to do with sex itself but their genes are linked with those of sex. Morgan has found a large number of such sex-linked characters in the pomice fly, *Drosophila melanogaster*, among them eye-color, body-color, wing characters, etc. Other well-known cases are Daltonism or color blindness and hemophilia or slow clotting of blood in man.

Such sex-linked characters are like recessive ones in that they do not develop when balanced by a normal allelomorph. Consequently they do not develop in females unless they are inherited from both parents, their genes being present in both

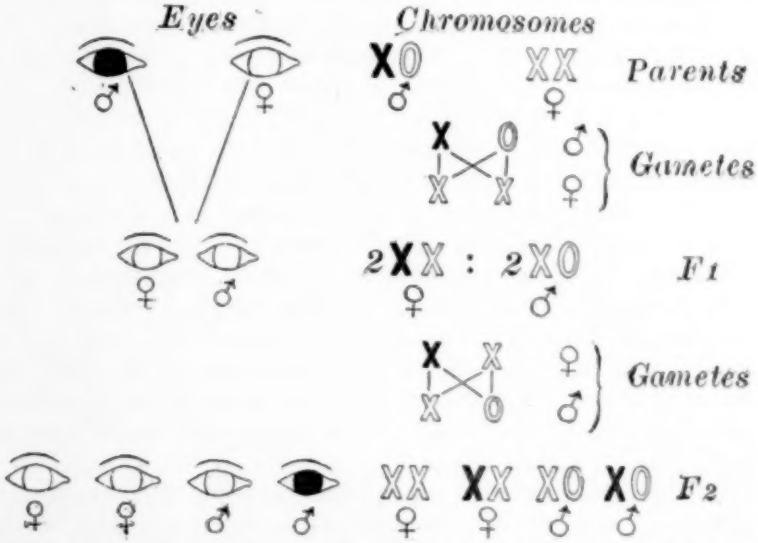

FIG. 18. DIAGRAM OF SEX-LINKED INHERITANCE OF COLOR-BLINDNESS (DALTONISM). A color-blind male (here black) transmits his defect to one half of his grandsons only. The corresponding distribution of the sex chromosome containing the gene for this defect is shown on the right. (After Morgan.)

X chromosomes, whereas in males they are always inherited from the mother only since the single *X* chromosome of the male always comes from the mother. All the sons of a color-blind father and normal mother are normal since the single *X* chromosome which they have comes from the mother and carries the gene for normal vision. All the daughters of such a cross appear normal, although carrying the paternal gene for color-blindness, since they also have from their mother the gene for normal vision. Half of the germ cells of these daughters carry the gene for color-blindness, half for normal vision and if one of the former kind is fertilized by a male-producing

sperm it gives rise to a color-blind male since in this case the gene for color-blindness is not balanced by a normal allelomorph; consequently half of the sons of the F_2 generation will be color blind (Fig. 18).

(*f*) *Abnormal Distribution of Chromosomes and Factors.*—Experimental evidence that the chromosomes are the seat of inheritance factors is found in the correlation between the abnormal distribution of chromosomes and the development of abnormal characters in the embryo or adult. An abnormal distribution of chromosomes to the cleavage cells may be caused in a variety of ways but one of the least injurious methods of accomplishing this is by causing two spermatozoa instead of one to enter an egg. In such doubly fertilized eggs Boveri discovered that different cleavage cells receive a different number of chromosomes and in general those cells which receive the largest number develop most typically, while those which receive a small number develop atypically. By a skillful analysis Boveri proved that normal development depends not so much upon the absolute number of chromosomes in a given cell as upon a complete set of all the different kinds of chromosomes, and when a complete set was not present certain characters were lacking in development. By this means he showed that different chromosomes of a set differ in hereditary value, as, for example, the fingers of a hand differ from one another, and that two chromosomes of one kind could not make up for the lack of one of another kind, any more than two thumbs could make up for the loss of a little finger.

A still more detailed correlation between the presence or absence of a particular chromosome and the presence or absence of particular characters in the developed organism has been described by Bridges (1916). In his study of the pomice fly, *Drosophila melanogaster*, he found that the occasional appearance (1 in 1700) of a matroclinous daughter or patroclinous son was due to the fact that the *XX* pair of chromosomes fail to separate in the reduction division of the egg so that both *XX*'s are included in the egg (Fig. 20, *C*) or both are extruded in the polar body, or the *XY* pair fail to separate in the reduction division of the sperm so that one sperm may have both and another lack both of these chromosomes. This phenomenon he calls "non-disjunction" and it results in the production of matroclinous daughters or patroclinous sons, and in many other irregularities of inheritance which follow precisely the abnormal distribution of these chromosomes. A patroclinous son is the result of the fertilization of an *O* egg by an *X*

sperm; such an *XO* son is sterile whereas the normal *XY* son is not, thus showing that the chromosome *Y* has some function though apparently it does not contain any of the genes; fertilization of an *O* egg by a *Y* sperm produces a combination (*YO*) which is non-viable. Fertilization of an *XX* egg by a *Y* sperm produces a matroclinous daughter (*XXY*), whereas fertilization of an *XX* egg by an *X* sperm produces a combination (*XXX*) which is non-viable. These relations are shown schematically in the accompanying diagrams (Fig. 19).

Finally the most notable correlation between abnormal distribution of chromosomes and the development of abnormal

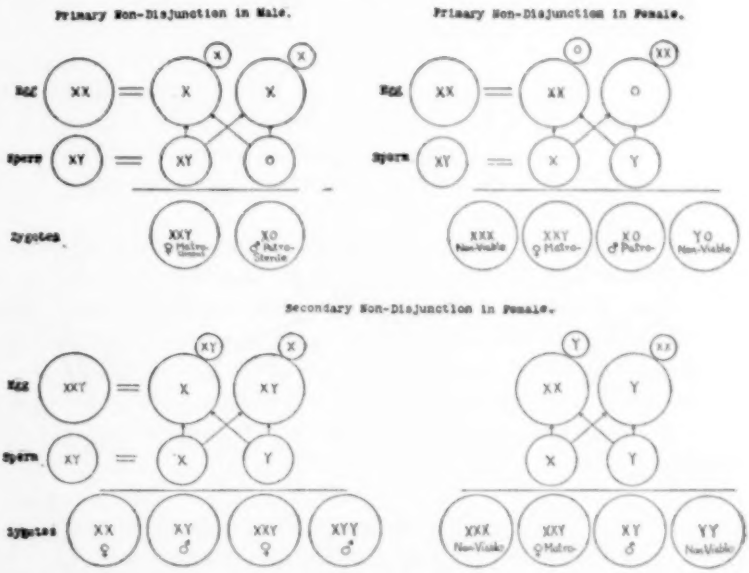

FIG. 19. DIAGRAM OF NON-DISJUNCTION OF SEX CHROMOSOMES (BRIDGES) IN THE MATURATION OF THE EGG AND SPERM AND THE RESULTING TYPES OF ZYGOTES.

characters has been found by Morgan in gynandromorphs or sex-mosaics of *Drosophila* in which one portion of the body has the characters of the male and another those of the female. Such sex-mosaics are evidently due to the fact that in the ordinary somatic cell-divisions the pair of *XX* chromosomes in the female or of *XY* chromosomes in the male do not go into every daughter cell but are so distributed that two *X*s (female constitution) occur in some cells and one *X* (male constitution) in other cells.

All of these cases of abnormal distribution of chromosomes coincide exactly with the subsequent abnormal distribution of

characters in the developed animal and they prove that the inherited factors for these characters are located in the chromosomes.

(*g*) *Linkage of Characters and Chromosomal Localization.*—Finally the study of characters which are linked together in heredity, joined with the study of the chromosomes and their distribution in the maturation and fertilization of the germ cells, has not only confirmed the chromosomal theory of heredity but has also shown that certain chromosomes carry the genes for certain characters and has even indicated the relative positions of different genes in the chromosomes.

In higher animals and plants the number of chromosomes is small as compared with the number of their Mendelian factors, and therefore if these factors are located in the chromosomes each must contain several of them. Since chromosomes generally preserve their identity or individuality the factors which they contain should be linked together and developed characters should be inherited in groups corresponding in number to the different chromosomes.

It has been known for a long time that certain characters are correlated so that they usually go together although they may have no evident dependence upon one another. Thus Darwin mentions the fact that male albino cats with blue eyes are usually deaf and have defective teeth. Many other cases of the association of peculiar characters were reported by earlier and later observers but the causes of such correlations were wholly unknown.

Since 1910 Morgan and his associates have discovered more than one hundred new characters, or mutations, in the pomice fly, *Drosophila melanogaster,* which are linked together into four groups, corresponding to the four pairs of chromosomes in this species. Up to 1916 they had located in the first group 47 different characters, in the second 27, in the third 22 and in the fourth 2.

Corresponding with the number and size of these groups there are four pairs of chromosomes in *Drosophila,* three of which are large and one is very small (Fig. 20). The sex chromosomes (*XY* in the male, *XX* in the female) constitute one of the large pairs and the genes of the characters which are sex-linked are located in these chromosomes; the genes of the second and third groups of characters are presumably in the other large chromosomes, while the fourth group of only two characters probably have their genes in the very small chromosomes. If this interpretation is correct, linkage is due to the

grouping together of certain genes in certain chromosomes, there are as many groups of characters as there are pairs of chromosomes and as long as the chromosomes preserve their individuality the linkage of genes in the chromosomes and of characters in the developed organism will persist.

"Cross-Overs."—But linkage of inherited characters is not quite so simple as this statement would indicate for an extensive study of this phenomenon in *Drosophila* has shown that while characters are usually inherited in the same groups this is not always true. For example, Morgan has found that when a female fly with white eyes and yellow wings is crossed to a male with red eyes and gray wings all the sons are yellow and have white eyes while all the daughters are gray and have red eyes, but when these latter are crossed 99 per cent. of the offspring show the same linkage of the colors yellow-white, gray-red, but in 1 per cent. the linkage is yellow-red, gray-white.

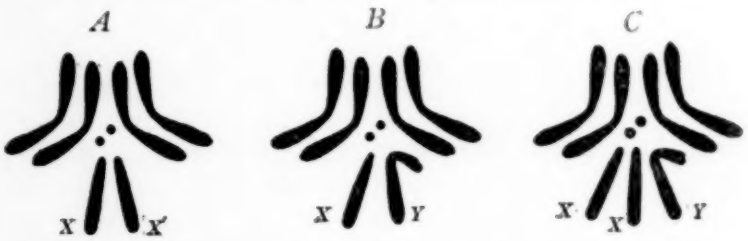

FIG. 20. CHROMOSOMES (DIPLOID NUMBER) OF *Drosophila melanogaster*. *A*, Female with 2 *X* chromosomes; *B*, Male with 1 *X* and 1 *Y*; *C*, Matroclinous female resulting from non-disjunction of the 2 *X* chromosomes of the egg. (After Morgan.)

This interchange of characters in the two groups, or "cross-over" as Morgan calls it, may be explained by assuming that there has been an interchange of genes between the two sex chromosomes of the female; "cross-overs" do not occur in the male of *Drosophila*. Janssens has found that when the paired chromosomes lie side by side in synapsis they sometimes twist around each other and in their subsequent separation each chromosome sometimes breaks at the point where the two cross and a portion of one chromosome is thereafter joined to the other one. In this "chiasmatype" of Janssens we have a relatively simple explanation of the interchange or "cross-over" of genes and consequently of the breaking up of old groups of characters and the establishment of new ones. Similar regrouping of characters takes place in each of the other three groups of *Drosophila* and can be explained in the same way (Fig. 21). If chromosomes of a pair are twisted round each

other at more than one place and are then broken at these points we get double or multiple crossing-over and a corresponding re-grouping of genes and of characters. Unless a pair of chromosomes are very tightly twisted two cross-overs will not occur near together and in general the farther apart points are in a chromosome the more likely is a cross-over to occur.

All genes which are linked to each other lie in the same chromosome and Bridges (1914) has shown that the farther apart in a chromosome any two genes lie the greater is the

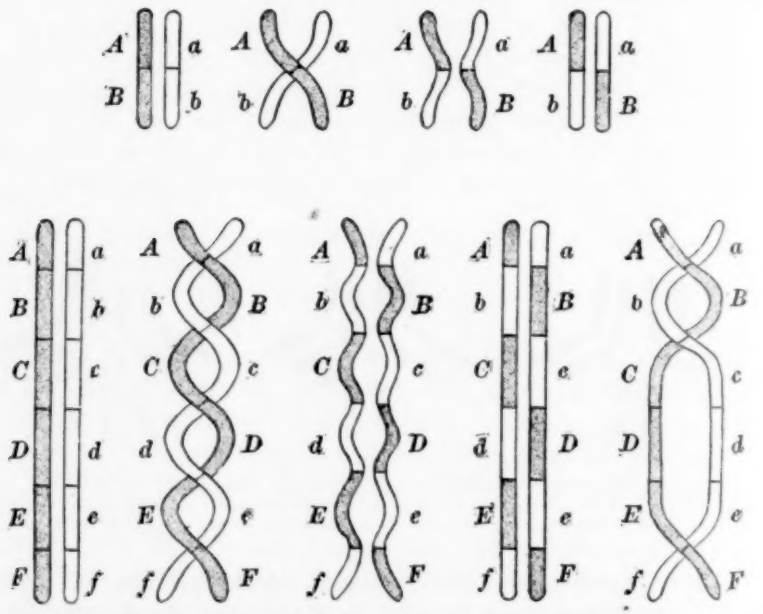

FIG. 21. DIAGRAM OF THE PROBABLE MECHANISM OF "CROSSING-OVER." Pairs of homologous chromosomes, one from the father the other from the mother, are shown in synapsis; on the left they lie parallel to each other and when they separate they remain as they were before union; in the second column they are shown crossing each other one or more times; in the remaining figures are shown the results of the chromosomes breaking at the points of crossing, thus interchanging sections of the two chromosomes. Letters indicate *loci* of homologous genes in the two chromosomes of a pair. (After Wilson.)

amount of crossing-over between them. Morgan takes 1 per cent. of crossing-over as the "cross-over value" and in general this may be used as the unit of distance between genes in the same chromosome. If cross-overs between two genes take place only in one case out of a hundred (1 per cent.) the genes are supposed to be separated by only one (1) unit of distance; if in thirty cases out of a hundred (30 per cent.) they are separated by thirty (30) units, etc. And when the relative num-

bers of all cross-overs are considered it is possible to construct a "map" of the chromosomes, as Morgan has done, showing the relative positions and distances apart of all the genes concerned.

Such a map represents only an approximation to the truth since certain conditions may change the percentage of cross-overs; thus Sturtevant has found that "factors for crossing-over" may be present in certain cases which modify the expected percentages, and Plough has shown that crossing-over may be increased by high temperatures, and that it takes place only in the *early oocyte* stage when the chromosomes are fine threads. Nevertheless these modifications of the percentages of cross-overs do not appear to invalidate the calculations as to the relative positions of genes in a chromosome.

Castle (1919, 1920) maintains that Morgan's evidence does not support the hypothesis of the linear arrangement of genes in a chromosome and he attempts to show that an arrangement of genes in three dimensions of space around the chromosomes is a more likely hypothesis. Without entering into the details of his argument it may be said that the longitudinal splitting of chromosomes, the equal division of genes, and the union of chromosome pairs in synapsis during the slender thread stage seem to admit of no other explanation than a linear arrangement of genes in the chromosome.

This work of Morgan and his associates on the localization of genes is in all respects the most remarkable work which has ever been done in this field; for the first time it gives us a detailed picture of what Weismann called the "architecture of the germplasm"—for the first time it assigns to different genes "a local habitation and a name."

(*To be continued*)

A GRAPHIC METHOD OF MEASURING CIVILIZATION, AND SOME OF ITS APPLICATIONS

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IN his interesting book, "Civilization and Climate" (Yale University Press, 1915), Dr. Ellsworth Huntington has essayed to map the degrees of civilization of the whole world, and the United States in particular, and to correlate these with certain rather complex climatic factors which he had ingeniously worked out. He used several different methods for measuring civilization, but relied chiefly on a sort of composite picture of the opinions of fifty correspondents of wide experience in various parts of the northern hemisphere, supplemented by his own observations in many lands, and some independent statistical data.

Each collaborator was asked to assign a sort of percentage rating in the scale of civilization to each of the principal geographical unit areas of the world (185 in number), and the results were then averaged and mapped. These individual opinions were doubtless based on general impressions of characteristics not easily weighed or measured, and the emphasis given to each characteristic naturally varied with different collaborators. One of them took the trouble to tabulate his estimates for a few countries in considerable detail, mentioning such attributes as initiative, inventiveness, ability to carry out large projects, attention paid to education, hygiene and morality, and appreciation of the beauties of nature, art, and literature.

For the United States alone (presumably because similar statistics were not available for many other countries) Dr. Huntington supplemented the opinions of his correspondents with statistics of mortality, illiteracy, school attendance, and distinguished persons,[1] and suggested the possibility of using for the same purpose criminal records, railway mileage, postal business, and manufacturing. For comparing the efficiency of whites and negroes in one of the early chapters he set forth the results of certain psychological tests of school children, earn-

[1] An interesting early contribution to this subject is an article by Hon. Henry Cabot Lodge on the distribution of ability in the United States, in the *Century* (20: 687–694) for September, 1891.

ings of workers in specified industries, and certain census data for the farms of the two races in selected groups of states, some northern and some southern.

The final results in each case agree reasonably well with each other and with what a well-informed reader perusing the book for the first time might expect, as well as with the climatic factors used. But in the discussion of the civilization maps the reader is left in doubt as to whether any or all of the fifty collaborators took into consideration the whole population of each country or only the upper strata.

One would not have to go very far afield to find communities in which the adult population is relatively homogeneous with respect to the characters that make up civilization, analogous to a prairie in which most of the mature plants are of about the same height, and others with considerable numbers of both celebrities and "undesirable citizens," a condition analogous to a forest with tall trees, lowly fungi, and various intermediate forms.[2] Every large city has its cultured aristocracy and its slums, and a person relying on statistics of illiteracy, pauperism and crime for measures of civilization might rate such a city lower than a thriving rural community, while one looking only at the achievements of the most prominent citizens would put the city the higher. In some of the southeastern states a century ago about half the population consisted of illiterate slaves, but the "quality folks" gave these same states a higher standing in the eyes of the world than the more newly settled middle western or north central states, with their then much more homogeneous population.

It is evident therefore that in order to get a fair measure of civilization we must eliminate personal opinions as far as possible and find one or more rational tests that can be applied to the whole population or the greater part of it; or better still, instead of merely taking averages, devise curves to show the range of variation in each community or group studied. For most such data we must look to the government census reports, but some are more readily obtainable from other sources, and some not at present available at all except for a few small groups may possibly be returned by future censuses.

The statistics that may be used as criteria of civilization might be divided roughly into two classes, namely, institutional and individual. The former are obtained from corporations, organizations, public officials, etc., and include such matters as

[2] See article on plant sociology in the SCIENTIFIC MONTHLY (4: 456–460) for May, 1917.

aggregate and per capita wealth; manufacturing, banking and insurance; railway mileage, number of newspapers, telephones, automobiles, libraries, etc., per capita or per square mile; church membership, school attendance, pauperism and crime.[3] Individual statistics are based on inquiries made of or about all individuals (or at least all adults, voters, or heads of families), and may include, among other things, number of persons per unit area, distance of residence from birthplace, age, marital condition, education, and occupation. (Wealth and church membership could indeed be ascertained from individuals, but our census has never been so inquisitorial.) The statistics of agriculture occupy an intermediate position, for the average farm is commonly a one-family institution.

Almost any of the kinds of institutional statistics could be used as a rough measure of civilization, but different kinds might conceivably give quite divergent results. Some very significant data about the civilization of rural districts can be obtained from agricultural statistics, such as the value of farm buildings, the proportion of farm land that is cultivated, the value of crops per acre, etc., but that tells us nothing about conditions in cities, and need not be considered further at present.

Some of the individual statistics, such as those of age and marital condition, do not vary much with the progress of civilization, while others, like illiteracy, give us only one average (or as many averages as there are groups used), without telling how far any individuals depart from that average. If, however, we have criteria in which each individual is given a rating, and the number of persons between any two points on the scale is known, we can look at the matter in a two-dimensional way and construct characteristic curves for each community or group. The census has long been giving us information of this sort about the ages of the population, but as just stated that is of little or no service in measuring civilization, the age curves for all sufficiently large populations being very similar.

The two most promising criteria for making civilization curves seem to be education and occupation; but unfortunately the treatment of these in our censuses hitherto has not been very satisfactory. About the only inquiry on existing census schedules about the education of the adult individual is whether or not he can read and write. It would seem perfectly feasible and very desirable for the census demographers to recognize

[3] It has been suggested, though perhaps not altogether seriously, by some chemists that the amount of soap or of sulphuric acid used by a nation is a pretty good measure of its civilization.

several grades of education instead of only two, separating those who have been through high school or college from those who have not, and so on, or simply to ascertain how many years of schooling each person has had. If errors were made by the enumerators they would balance to a considerable extent in the final summing up, and even if many individuals remained wholly unclassified as to education, significant ratios could still be worked out from the returns for the others. The results of such an inquiry could of course be further segregated according to race, sex, and age, like the present illiteracy data, or restricted to adults if desirable.

As far as occupation is concerned, recent censuses classify workers minutely enough by industries, but not very satisfactorily by grades of work, so that one would have trouble in determining from the returns the number of idlers, unskilled and skilled laborers, clerks, foremen, proprietors, etc., in a given community. There should be no special difficulty, however, in preparing schedules that in addition to classifying the workers by industries as heretofore would put each individual into a certain grade. If we fix the number of grades at ten for convenience they might be divided as follows:

0. Persons who are a burden to society, such as criminals, imbeciles, mendicants, vagrants, and paupers.

1. Unemployed but harmless persons, such as children, students, invalids, gentlemen of leisure, and aged people.

2. Unskilled laborers, who work mostly in gangs, under more or less constant supervision, with a minimum of responsibility.

3. Here may be put three fairly distinct groups, which are of approximately equal rank, but could be separated if more than ten grades were used. First, men who require no more education than the unskilled laborers, but have more responsibility, and work much of the time alone, and thus have opportunity to cultivate their powers of observation and develop resourcefulness. *E.g.*, woodsmen, fishermen, farm hands, miners, cowboys, teamsters, boatmen, trainmen. Second, semi-skilled laborers, who require usually a few weeks to become proficient in their work, such as factory operatives, motormen, chauffeurs, locomotive firemen, and house-painters. Third, persons who have some responsibility, financial or otherwise, but little or no authority other than that involved in keeping order or guarding property, and do not need much education. Examples are clerks of various kinds, agents, salesmen, small merchants, policemen, city firemen, soldiers, and janitors.

4. Skilled laborers, who have learned a trade by a period of

apprenticeship, or by a few months of study. Some of the less obvious examples are stenographers, bookkeepers, telegraphers, locomotive engineers, pilots, musicians, cooks, interpreters, printers, sign-painters, and photographers.

5. Persons in authority, having some executive ability, but not requiring any originality or higher education, and not elected by the people. *E.g.*, foremen, managers, chief clerks, sea-captains, manufacturers, contractors, bankers, capitalists, and proprietors of hotels, large stores, plantations, etc.

6. Professional men and experts, mostly college graduates, who have qualified for their work by a special course of study lasting a year or more; such as lawyers, architects, civil engineers, foresters, chemists, and physicians. Many if not most of these do not work on a salary basis, but get their remuneration irregularly from a large number of clients or patients.

7. Altruistic public servants, who work for several or many people simultaneously, and influence them for good at little or no cost to each individual benefited. To this class belong most if not all educators (perhaps excluding young teachers of limited experience who are not making that their life work), clergymen, missionaries, journalists, lecturers, and philanthropists. In education they rank about equally with those in class 6, but their ideals are usually higher, and their remuneration less in proportion to the value of their services than in any of the preceding classes.

8. Public officials and statesmen, elected by the people, or holding high appointive positions, like judges, ambassadors, commissioners, and cabinet members. Perhaps presidents of colleges, railroads, large corporations, etc., and elected officers of nation-wide organizations, should be included in this class, and officials of small communities, who have some other business that takes up most of their time, excluded.

9. Persons whose chief occupation is adding to the sum of human knowledge, or writing or doing things that have not been said or done before,[4] such as investigators, explorers, inventors, scientists, poets, novelists, humorists, cartoonists, composers, artists, "empire builders," and perhaps even holders of world records in athletics. It is on this small class, constituting (in the United States something like one ten-thousandth of the total population, that the progress of civilization mainly depends.

[4] New ideas, methods or principles should be the test rather than mere new facts, otherwise newspaper correspondents, detectives, crop reporters, census enumerators, tax assessors, surveyors, etc., would have to be put in this class. But almost every one who habitually writes books or magazine articles (other than mere hack-writers) or composes music or poetry or turns out inventions or works of art belongs here.

There will doubtless be some difference of opinion as to the relative rank of some of the occupation classes just outlined, but in a general way those in the higher classes have the most education and the widest spheres of influence, and are fewest in number, as will be shown by some of the curves selected for illustration farther on.[5] As a rule persons in any one of the grades have passed through some or most of the grades below it before attaining their present positions; but this is not a strict linear sequence like the educational grades, for classes 0, 4, 6 and 8 are more often side branches with no outlet than stepping-stones to something higher. Or to put it in another way, many persons reach groups 5, 7 and 9 without passing through those immediately below.

Of course it is impossible to draw sharp lines between the different occupation groups, on account of the endless variety of occupations in our complex civilization,[6] and also because there are at all times large numbers of persons in a state of transition from one group to a higher one. But such difficulties are inherent in almost all classifications, and need not be regarded as insurmountable. (Very similar difficulties are encountered, for example, in defining the zones of vegetation on the slopes of a high mountain; and in the case of a complex mountain system, with a considerable variety of soil and exposure conditions, it may not always be certain which of two non-contiguous zones is the higher.)

To apply the criteria here proposed to the measurement of civilization, let us suppose that each individual in the community and group under consideration (be it total population or only adults, natives, whites, males, or some other restricted group) has been given a decimal rating in education and occupation.[7] The sum or average of the two might be called his civilization number or coefficient. A curve could then be con-

[5] The results of a psychological rating for United States soldiers taken from a number of different occupations in civil life, published in *Science* for March 14, 1919 (page 358), agree pretty well as far as they go with the sequence here adopted. Even the Russian Bolsheviki are reported to have grouped the workers of that country a few months ago into about thirty categories in ascending order, with fixed salaries for each, ranging from 370 rubles per month for apprentices and beginners to 2,200 for certain public officials. Their classification, as published in some of our daily papers, bears some resemblance to the one here proposed (which was worked out in nearly its present form in the summer of 1917, but not published until now). Confucius is said to have divided the workers of China into four grades over two thousand years ago.

[6] The last United States census recognized about 17,000 different occupations for purposes of enumeration, and assembled them in 428 groups in the published returns.

structed having for its ordinates the civilization numbers, and for its abscissas the number or percentage of persons ranking at and above any given number. With a decimal rating in two different lines we would of course have instead of a curve a series of twenty steps of the same height and varying width, but if the number of grades were increased the steps would approach more nearly to a smooth curve, steepest among the higher grades, like a similarly constructed curve for the ages or wealth of the population, cities or farms arranged in order

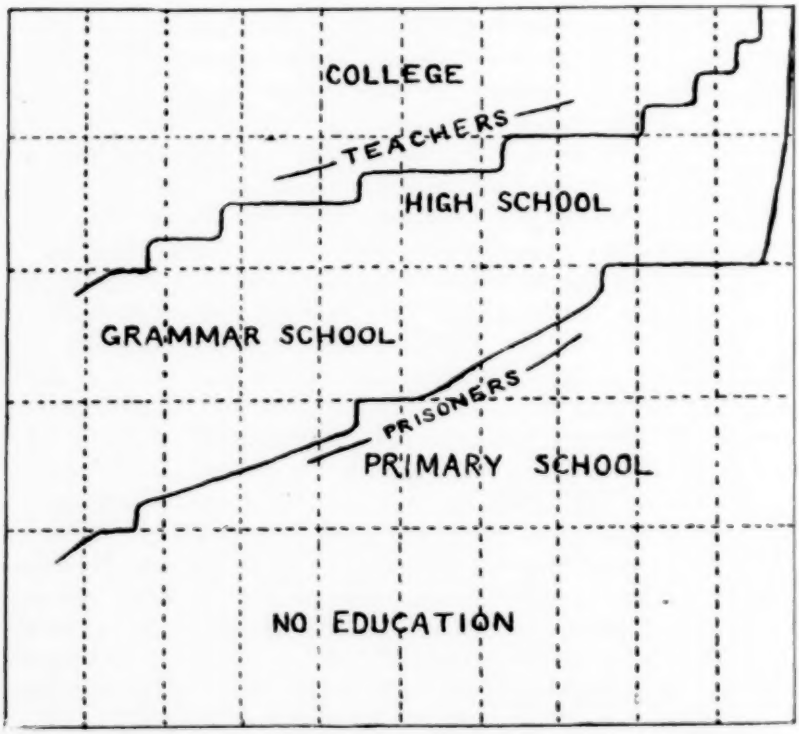

FIG. 1. EDUCATION CURVES FOR 3,648 ALABAMA TEACHERS AND 2,500 INDIANA PRISONERS, BASED ON 1919 STATISTICS.

of size, species of trees in a forest in order of abundance, and many other things easily called to mind.

To illustrate the workings of the system two graphs are presented. As there seem to be as yet no available data giving both education and occupation simultaneously for any considerable portion of the population, the two kinds of ratings are treated separately.

[7] If it were possible to add psychological tests to the educational and occupational inquiries here proposed we might have a still more satisfactory measure of civilization.

In both graphs horizontal distances represent percentages, and the vertical lines divide the figures into ten equal parts to facilitate measurement. On any horizontal line the distance from the point where a given curve intersects it to the right-hand edge of the figure represents the percentage of the total number who rank above that point, and *vice versa*. The average rank of any curve is of course proportional to the area between it and the base. Nearly all the persons on which these curves are based are adults; but if the total population of any normal community were graded in this way the large number of children would probably make the uneducated and unemployed classes the largest.

The first graph rates according to education two groups far apart in the social scale, namely, 3,648 rural and village teachers (including both white and colored) in Alabama, and 2,500 inmates of the Indiana State Prison. The figures for teachers are taken from Bulletin 41, 1919 series, of the U. S. Bureau of Education, and those for prisoners are from a newspaper abstract, published last spring, of an article by Dr. Paul E. Bowers of the institution named.[8]

Vertical distances in the education graph represent the amount of schooling, on the assumption that a normal individual who goes through college enters school at the age of six and spends four years in each of the four divisions indicated, graduating at twenty-two. Each curve in this case represents a single occupation group (number 7 in one case and 0 in the other), so that if education and occupation were being rated simultaneously the curves would still be of the same shape, but farther apart.

[8] Very likely some additional data of this kind could be found, but these are all that have come to the writer's notice recently. There are some educational statistics in "Who's Who in America," but they give only two or three points on the educational curve, and about half the persons listed in that work are college graduates, not further classified as to education.

If we could construct an education curve for the whole adult population of the United States it would doubtless lie between the two shown in Fig. 1. As pointed out above, the census gives us only one point on such a curve, namely, the percentage of illiterates. In 1910 the illiteracy percentage for adult males of all races and nativities was 8.4 in the whole United States (24.3 in Alabama and 4.1 in Indiana). The number of college graduates for the whole country—but not for single states—can be estimated approximately from the table of colleges in the New York World Almanac. From that it appears (after making due allowance for omissions) that there are something like a million living college graduates in the United States, which is about 1 per cent. of the total population or 2 per cent. of the adult population. Or if the sexes were separated it would probably be found that about 3 percent. of the men in this country are college graduates.

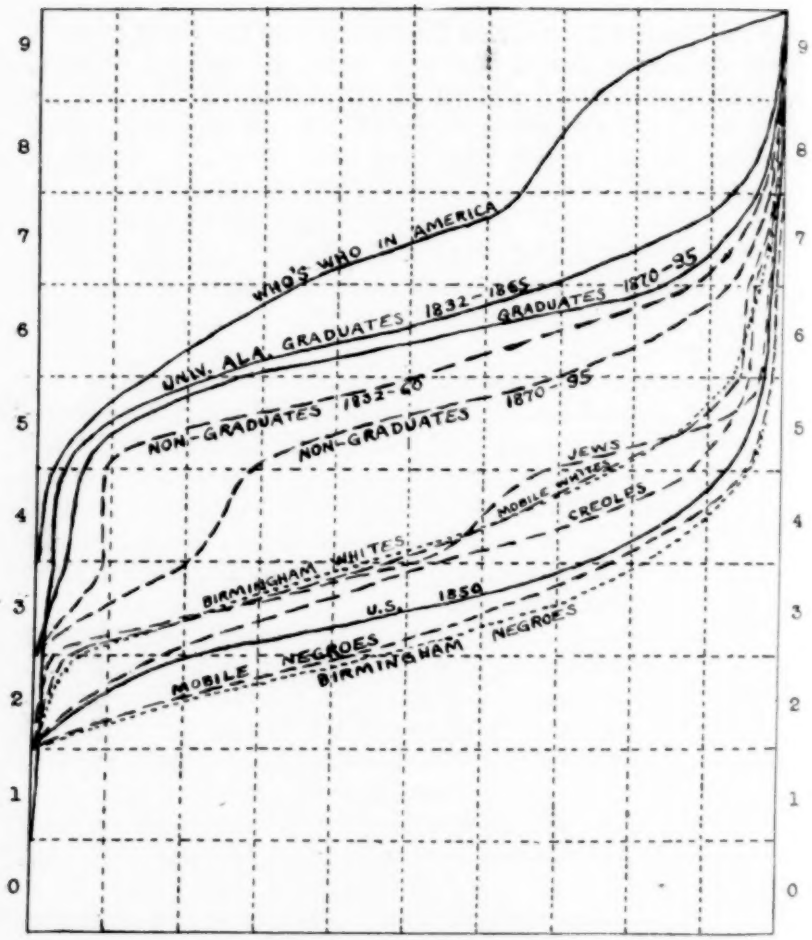

FIG. 2. OCCUPATION CURVES FOR THE FOLLOWING TWELVE GROUPS.

1. First 1,000 names in "Who's Who in America," 1916 edition, excluding a few cases difficult to classify.
2. 373 graduates of the University of Alabama, 1832–1865.
3. 674 graduates of the University of Alabama, 1870–1895.
4. 586 non-graduates of same, 1832–1860.
5. 1005 non-graduates of same, 1870–1895.
6. 959 white persons in Birmingham, Ala., whose names begin with A. (1913.)
7. 527 negroes in Birmingham, Ala., whose names begin with A.
   (The Birmingham curves are dotted lines.)
8. 564 white persons (including Jews and Creoles) in Mobile, Ala., selected from first part of alphabet.
9. 281 supposed Jews in Mobile.
10. 156 Creoles in Mobile.
11. 749 negroes in Mobile, selected from first part of alphabet.
12. 5,307,347 free males over fifteen years old, gainfully employed in the United States, 1850.

The numbers at the sides correspond with the occupational groups defined in the text.

The second graph is based on occupation only, and includes twelve different curves. The vertical distances correspond with the ten occupational grades above outlined, and are numbered accordingly. For the sake of simplicity it is assumed that each step on the occupational ladder is of the same height, there being apparently no rational method of determining how much they should differ, if any.[9] And for the sake of appearances all the curves are drawn as smoothly as possible, on the assumption that no two persons are of exactly the same rank, and that there are all gradations between the highest and the lowest. For any one curve the number of persons in any occupational group is measured by the horizontal distance between the points where it cuts the upper and lower boundaries of the group; so that gentle slopes indicate large numbers and *vice versa*.

The uppermost curve in this graph is based on the first thousand names in the 1916 edition of "Who's Who in America," and probably does not differ noticeably from that which might be derived from the last thousand or any other large number in the same work. It would have been comparatively easy to construct separate curves for men and women, married and single persons, natives and foreigners, persons with German, Jewish, Irish or Scandinavian names, different age groups, residents or natives of different states, or of cities and rural districts, and those with different religious or political affiliations (where such are indicated), but that would have taken considerable time and complicated the graph too much.

The next four curves are based on graduates of the University of Alabama, and matriculates who did not graduate, both living and dead, in two different periods of approximately equal length, before and after the Civil War. The data are taken from an alumni catalogue published in 1901. Those whose occupations were unknown to the compilers of the catalogue, or who died before embarking on their life work, have been left out of the calculations, so that practically none falls in the unemployed class except a few retired business men.

The higher rank in civilization of graduates as compared with non-graduates is just what one would expect, and illustrates graphically the effect of higher education. The higher

[9] It is possible, however, that it would be nearer the truth to make the upper steps wider, for there seems to be greater diversity of ability among the higher classes than among the lower. For example, one unskilled laborer is about as good as another, which can not be said of managers, teachers, or scientists. And it is easy to prove by means of statistics of illiteracy, farm building values, etc., that in those parts of the United States having a large colored population there is more variation among the whites than among the negroes, even where the latter are decidedly in the majority.

rank of the ante-bellum students, both graduates and non-graduates, may be due to more than one cause, but the principal one is doubtless that at the time the record was made, in 1901, many of the students of 1870 to 1895, especially the later ones, had not reached as high a station in life as they did later. This is borne out by the comparatively large number of public officials among the ante-bellum graduates—for one does not usually get elected to public office until middle life—and by the number of post-bellum non-graduates still in the clerk and book-keeper classes in 1901.

The continuous curve below the middle of the graph is for all white and free colored males over fifteen years old in the United States returned by the Seventh Census as having gainful occupations in 1850; they are 5,371,876 in number, from which however have been deducted 64,529 that are hard to classify. That census recognized 325 different occupations, most of them designated by only one or two words, and all arranged in an alphabetical list with the number of workers assigned to each. (Similar data were also given for each state.) With occupations so briefly characterized it is often difficult to determine the proper rating, and it is pretty certain that two or three different grades are sometimes combined under a single word, such as agents, dealers, farmers, jewelers, lumbermen. But the errors of judgment tend to balance each other to a considerable extent when so many are involved, and the resulting curve harmonizes very well with others near it. Similar curves could be constructed for separate states and later censuses, thus affording opportunities for some interesting comparisons.

The remaining six curves are derived from the 1913 directories of Birmingham and Mobile, Alabama, both published by the same company.[10] In order to make these curves comparable

[10] R. L. Polk & Co., of Columbus, Ohio. A city directory usually lists about a third of the total population, mostly adult males. Wives are not mentioned at all in the Mobile directory, but in that for Birmingham their existence is indicated by their first names in parentheses following the husband's names (in the case of the white population; among the negroes the married men are indicated by a special symbol, but the wives' names are not given). In both directories the occupation, if any, of each person listed is given in a word or two (usually abbreviated), and even less explicity than in the 1850 census above mentioned, so that there is room for many errors of judgment; these, however, must neutralize each other to a large extent in the final summation. Persons whose occupations are not given seem to be mostly widows keeping house for their children, and young ladies not employed outside their homes.

The criminal class of course does not figure as such in these directories (or in census enumerations), because some of them have unmentionable occupations, some have no fixed habitation and thus escape enumeration, and some are confined in penal institutions.

with others the unemployed persons are disregarded, for there is no sure way of distinguishing between the busy housekeepers on the one hand and the debutantes, society women and superannuated people on the other.

The Birmingham directory puts all names in a single alphabetical list, designating negroes by a star before the name. The Mobile directory lists the two races separately, and in the list of whites uses a special symbol for the Creoles, who constitute a little more than 1 per cent. of the whites or about ¾ of 1 per cent. of the total population (but have never been distinguished in census reports). The curves for whites and negroes in both cities as presented here are based on only a few hundred names at the beginning of the alphabet, but the results are probably accurate enough for present purposes.

For Mobile there are given here two additional curves, one for Jews and one for Creoles. The number of Jews in this or any other American directory can not be estimated very accurately, but they were identified as far as possible by their names, all the way through the alphabet.[11] And even if a large number were overlooked in the count that should make no particular difference in the occupation percentages. The count of Creoles aimed at completeness. The whole number of them found in the directory was less than 200, and eliminating those whose occupations were not given left only 156, rather a small number for accurate results, but the curve lies between those for whites and negroes in the same city, as we should expect. The curve for Jews also fulfills expectations in being strong in proprietors and clerks, and weak in skilled and unskilled laborers and public officials.

The contrast between whites and negroes in the proportion of unskilled laborers is very marked, as would be expected. Of course none of the college men or celebrities are in that class at all. One would have hardly expected so much similarity between the curves for the ancient seaport of Mobile and the modern manufacturing city of Birmingham, scarcely forty years old. The fact that the different curves do not cross each other much is rather significant.

A city directory naturally gives no direct information about the educational equipment of individuals, but even if it did and that had been utilized in constructing these curves—as should be done whenever it becomes possible—it probably would not change their shape much, for persons in the higher occupations commonly have the most education, as already stated.

[11] By this means it was estimated that Jews constitute about 2 per cent. of the white population or a little more than 1 per cent. of the total population of Mobile.

It is interesting to note that if the space for class 2 in the occupation graph were bisected by a horizontal line that would cut each curve at a point corresponding approximately to the illiteracy percentage of the group represented thereby;[12] which would harmonize very well with an assumption that half the unskilled laborers but very few of those belonging to the higher classes are illiterate.

Although the occupation data have been compiled rather hurriedly, without any attempt at extreme accuracy, the curves serve very well to illustrate the differences between several diverse population groups in a new way, and to demonstrate the validity of occupation as a test of civilization. If we had such curves for many different countries the knowledge should be extremely valuable for many purposes. For example, it would shed new light on the question of which nations are fitted for a popular government and which should remain monarchies or dependencies for some time to come. For a country or community with not more than half of its adult male population above the rank of unskilled laborers—a condition approximated by the two lowest curves, and probably also by Liberia, Haiti, Mexico, and several other tropical countries—could not be expected to govern itself very well if all the men had an equal voice in public affairs.

Some such point of view would have been useful in this country about two years ago, when large numbers of men were being classified for military service. Many of those shown by psychological tests or otherwise to be too low in intelligence were excused,[13] but little or no allowance was made for the few at the other extreme, men of higher grade than the lawmakers and military authorities (and therefore presumably too valuable for military service), except in the case of those above the age limit and a few special easily defined classes like clergymen and public officials.[14]

At various times in the last century or two, particularly in Russia since 1917, and in this country since the close of the recent world war, groups of men in occupation classes 2 to 4 (who are naturally not well grounded in the fundamentals of economics and sociology) have sought to divert by one means

[12] There are of course no illiterates among the "Who's Who" people and college men, and probably very few among the Jews, in the South at least. The illiteracy percentage for white and free colored persons over twenty in the United States in 1850 was given by that census as 10.35. That for adult males in 1910 in Birmingham was 2.3 for whites and 23.0 for negroes, and in Mobile 1.1 for whites and 25.1 for negroes.

[13] See *Science*, II., 49: 53–61, 221–226, 251–259, 1919.

[14] See B. E. Livingston, *Science*, II., 49: 202, 203, February 28, 1919.

or another to their own use some or all of the share of the profits of industry that rightfully belongs to the small minority of "bourgeoisie" who supply the brains or the capital, on the theory that those who work with their hands should have all the proceeds of their labor, and that mere numbers should dominate irrespective of ability, and regardless of how much inconvenience or injustice to innocent parties results from their selfish demands. Such attempts are rarely completely successful, however, for the obvious reason that civilization without competent leadership (classes 5 and upward) is impossible.[15]

When census methods become sufficiently refined so that civilization can be studied graphically in some such way as that here proposed for a long period of years, it will probably be found that the average rating of any one community, unless it is small enough to be affected materially by immigration and emigration, changes very slowly; although conceivably the shape of its characteristic curve might fluctuate locally or temporarily in response to educational and child-labor legislation or other influences. Although we seem to have made phenomenal progress in some lines in recent decades, it is chiefly in the sum total of human knowledge—that can be stored up and disseminated by means of the printing press, which did not exist a few centuries ago—rather than in individual efficiency.[16]

Some caution should be used in making comparisons by this method between different countries, or even different sections of a large country like ours, for it might not be fair to measure such different types of civilization as American and Japanese, or Yankee and Southern, by the same standards, at least until some more refined system is devised. But persons who have the time and inclination can easily give the plan a further trial with various city directories, alumni catalogues, biographical dictionaries, etc., without waiting for the census to take it up; and very likely many improvements can be suggested.

[15] If it was at all practicable it would be an interesting experiment to turn over to these insatiable toilers (some of whom have long been earning more than brain-workers who have far more education and experience and could make much better use of the money if they had it) for a time a few mines, newspapers, factories, railroads or islands, and see how long they could run them successfully without foremen, proprietors, experts, teachers, editors, lawmakers, inventors, writers, etc. Very likely sooner or later men would arise from the ranks of the laborers to fill these higher positions, but if so conditions would then be essentially the same as before the beginning of the experiment.

[16] In this connection see the abstract in *Current Opinion* (67: 106–107), for August, 1919, of a newspaper article by Dr. Charles Gray Shaw on knowledge as the cause of inefficiency.

FINIS CORONAT OPUS

By FRANK V. MORLEY

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THE evening vigil may be approached in many ways. Perhaps the pleasantest of all is to fortify the soul with plenty of tobacco, a canister of crackers and something potable to fall back upon, and a volume of the inimitable Robert Burton. But failing the "merry companionship" of the younger Democritus, we should be prone to choose the scientific remains of a poor, neglected, and forgotten scholar whose name was also Robert, but who was earlier in his unhappy life at Oxford by some fifty years.

It is scarcely unjust to say "forgotten"; save for a very occasional mention as the first in mathematics to use our present symbol for equality (and that is doubtful tenure upon fame!), who nowadays ever hears of Robert Recorde? Yet in its day "The Whetstone of Witte" was a famous book, the first treatise in English on arithmetic. It is affirmed that with the time of Recorde the English became conspicuous for numerical skill, and that after him the higher branches of mathematics began to be studied. But we can hardly say this was because of Recorde's work. As he prepared his book there was preparing another potent whetstone to activity, the Spanish Armada; his treatise was launched into a rising sea of intellectual interest, and the numerical skill of his contemporaries may have been due to their practise in dead reckoning and the impulses of trade, rather than to the direct influence of Recorde.

The generations which gave us Shakespeare and Spenser did not, however, give us much of scientific worth. Perhaps the interests were as yet too speculative, and the ideas too tenuous to avoid burial in argument. Until a statement is reducible to algebra, there will be no lack of polemics pro and con; and in those days algebra was treated as an empiric rather than an aid to thought. So Recorde, though he had a clear field ahead of him, yet handicapped himself by agreeing with his times.

But even among the scientists of his own day, Recorde stands nowhere as a creative figure. The restless and dis-

cursive Cardan, the silent Tartaglia, and the brilliant but lazy young Ferrari, were in an atmosphere far keener in research. Among teachers, many were better than our Oxford scholar. His reach was not great, and his mental footwork far from perfect. As a mathematician and as a medical man, we may let him pass; his contributions are hardly memorable enough for passage through the crowded centuries, save for their personal note. But here they breathe a sweet and a pathetic fragrance. His quaint and now archaic dialogues, the nice imaginary courtesies between the Master and the Scholar, his appeals to all those that love "honeste learnyngo," and above all, his sorry ending, make his a worthy case to ponder in the midnight hours.

There are various ways in which men have been done to death in their following of intellectual pursuits. There is a considerable band who suffered from an overdose of study, conspicuous with their young leader, Henry Kirke White. It was Henry, we remember, who was kept after school as a boy and consequently wrote

> How gladly would my soul forego
> All that arithmeticians know, . . .

When he went to Cambridge he was ranked as the best man of his year, in spite of the condition of his health, and mathematics was his only weakness. In mistaken kindness his tutors decided to keep him at work all summer on mathematics, instead of granting him the holiday which his epileptic case bespoke. And in July, while at work on logarithm tables, he was overtaken by a sudden fainting fit, with death following shortly after. Was anybody prosecuted for the flagrant case of homicide?

It was not overstudy which made an end of Robert Recorde in 1558, but rather what he calls the "sodaine unquietnesse" of the time. There is something appealing in the abrupt ending of his book. An abstruse discussion of universal roots is suddently thus interrupted.

Master. You saie truth. But harke, what meaneth that hastie knockyng at the doore?

Scholar. It is a messenger.

Master. What is the message? Tel me in mine eare.

Yea, sir, is that the matter? Then is there no remedie, but that I must neglect all studies and teaching, for to withstande these daungers? My fortune is not so good, to have quiete tyme to teache.

Scholar. But my fortune and my fellowes is much worse, that your unquietnes so hindreth our knowledge. I praie God amende it.

Master. I am inforced to make an eande of this mater: But yet will I promise you, that whiche you shall chalenge of me, when you see me at better laiser: That I will teache you the whole arte of universall rootes. And the extraction of rootes in all square surdes: with the demonstration of theim, and all the former woorkes.

If I might have been quietly permitted to reste but a little while longer, I had determined not to have ceased till I had ended all these thinges at large. But now, farewell. And applie your studie diligently in this that you have learned. And if I maie gette any quietnesse reasonable, I will not forget to performe my promise with an augmentation.

Scholar. My harte is so oppressed with pensivenes, by this sodaine unquietnesse, that I can not express my grief. But I will praie, with all theim that love honeste knowledge, that God of his mercie will sone ende your troubles and graunte you suche reste as your travell doth merite. And all that love learnyng say thereto, Amen.

Master. Amen, and amen.

These were the last words he printed. The message was a simple one, and familiar to teachers in all ages. It was a summons to the Fleet for debt. In days of pestilence and plague, this was equivalent to sentence to death by slow torture. Within the year disease had played its part, and he died among the miserable surroundings.

Poor Robert! He never got the "quietnesse reasonable" or the "better laiser" for performing his promise "with an augmentation." Nor did the charming affection shown by his scholar ever bear the fruits of future pupils. "God of his mercie" ended his troubles soon enough in death, but his gentle moan lives through the years as evidence of the passing of a kindly spirit, not a great one.

Half a century later, it is recorded in the Will of the other Robert that we spoke of, Robert Burton, that he gave a hundred pounds to his nephew, "nowe Prisoner in London, to redeeme him." Robert Recorde had no kindly uncle to play Democritus, and help him out. Well indeed might he have cried, *O viveret Democritus.*

Or, for that matter, well might we, nowadays.

ON RHYTHM.

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A PHENOMENON which may be called rhythmic is one that recurs at equal intervals of time or at any rate not at cognizably unequal ones. The dripping of water from a leaky tap is rhythmic, but the murmur of the brook is not. The universe is full of rhythms. The succession of the seasons, the alternation of day and night, the phases of the moon, the ebb and flow of the tide, the recurrence of spring and neap tides, the November flight of meteors, the yearly rise of the Nile, and so forth, are all examples of cosmic rhythms. The magnitude of the time interval or period of the rhythm is not of the essence of rhythmicality. Thus, the behavior of the ether in transmitting light waves is rhythmic, the frequency being only some billionths of a second; whereas the return of a comet such as Halley's to our solar system, although a matter of seventy years or so, is just as rhythmical; its reappearance is periodic.

Music is essentially rhythmic; in fact, it is the periodic character of the vibrations of the air that constitutes music as opposed to noise. The vibrations of the air objectively constituting noise are highly irregular or arhythmic.

A clap of thunder is not rhythmical. In a rhythm something recurs at equal intervals of time; if this something recurs at unequal intervals, the rhythm sometimes is spoken of as irregular. This usage would make the word "rhythm" synonymous with regular rhythm, which is the general acceptation and the one in which the term will be used in what follows. It is owing to the regularity of recurrence of eclipses, the equinox, meteors, comets, etc., that these phenomena can be predicted with an accuracy that makes astronomy as an exact science so justly admired. The periodicities of rhythms in the non-living world may be matters of years, months, weeks, days, hours, minutes, seconds or fractions of a second.

Coming now to the realm of Life, we find rhythms pervading everything. The plants, with striking regularity, have their own times each year for putting forth the buds, unfolding the leaves, bursting into flower and finally allowing all the perfumed beauty of the flower to fade in order that the fruit shall be formed as a life in death. Thus the poetess sang,

> "Leaves have their times to fall,
> And flowers to wither at the north wind's breath;
> Thou hast all seasons for thine own, O Death!"

In plain prose, there is no rhythm about Death.

"Chestnut Sunday" is approximately the same Sunday, and "Apple Blossom" week is practically the same week each year. The opening and closing of flowers is rhythmic, the rhythm depending on the waxing and waning of the intensity of daylight.

Doubtless the most familiar rhythms are in the world of animal life. Here we have rhythmic actions of animals as in flocks and herds, of animals as individuals, and of the organs, tissues and cells of the animal body. The migration of birds is annual in rhythm. It is only part of the truth to tell us that the waning light and diminished heat and food are what constrain the birds to leave us: they know *when* to leave us. Migratory birds which have spent all their lives well-fed in the captivity of Regent's Park, nevertheless become restless at the approach of autumn. Again, those animals which hibernate during the winter know when to betake themselves to their hiding-places, whence they come not forth until the spring.

The rhythm of the sexual activities of birds is one of the most characteristic things about their behavior. It is only in the spring that the "lovelier iris gleams upon the burnished dove," but it is *every* spring. Even a brainless (decerebrated) pigeon will "coo" energetically at the breeding season, although if the hen bird be placed near him he will take no notice of her. The sexual rhythm is inherent in the lower parts of the nervous system, but in the absence of the brain it is a meaningless and mechanical rhythm.

Practically all the activities of one's daily life are rhythmic; the most obvious perhaps being the regular alternation of waking and sleeping. There is a well-marked rhythm in our digestive organs, in the organs of excretion, and most pronouncedly in the beating heart.

Rhythm pervades the world of animal life: just watch that transparent jellyfish in the limpid summer sea, and you will notice how the edges of the umbrella contract or pulsate with slow and regular rhythm (about 30 in the minute). Equally obvious rhythms are those of the wings of birds and other flying things; of the legs in walking and dancing; of fins in swimming. Large birds fly with slow, leisurely rhythm, small birds with a fast one; just as tall men have a slow stride, short men a more rapid step. Regular rhythms are everywhere; if Nature abhors a vacuum, she also abhors fits and starts: living Nature does everything "decently and in order."

The periodicity of the heart's action is an excellent example

of a rhythm of animal origin. Seventy-two times in the minute this wonderful hollow muscle contracts (systole) on the contained blood forcing it out into all the arteries of the body, and seventy-two times in the minute does it dilate (diastole) and suck blood in from the veins leading to it. The duration of its cycle is therefore eight-tenths of a second (60/72), and in health during the many years of a long life it practically does not vary from this value. If, for more than a few minutes, the heart's rhythm remains distinctly irregular, then we conclude that something is amiss with this wonderful organ within our breast.

Sometimes we come across a heart with a congenitally fast rhythm, a condition called tachycardia, and sometimes one with an abnormally slow rhythm, a condition called bradycardia. Whereas the rhythm of the heart-beat is for each individual a certain average rate, it varies in different individuals according to height and age. Thus, tall persons have slower hearts than short people; and infants have a heart rate about twice as fast as adults. The whale and the elephant have very much slower heart-beats than the mouse or the sparrow. The heart-beat in these small animals is so fast that the pulse can not be counted in the usual way: until recently we had no reliable information about it, but by an electrical method used by a physiologist, Miss Buchanan, D.Sc., working in Oxford, it has been ascertained with great accuracy.

The pulse-rate, which is the same thing as the heart-rate, is very much slower in the cold-blooded than in the warm-blooded animals. Thus, in a fish or frog the heart contracts only about forty times in the minute, or about half the mammalian rate. This relatively slow rate can be quickened by making the heart beat in warm salt water, when the rate can be made to exceed that of the normal mammalian heart. A further study of the warm-blooded heart proves to be full of interest. It can be accelerated by warmth and slowed by cold; but it is its affectability by nerve impulses which is so remarkable. It is a matter of common knowledge that the heart can be made to beat much faster at one time and slower at another through nerve impulses alone. Everybody knows that emotions can influence the heart very markedly. Thus, of course, it has come about that "the heart" and certain emotions are taken as synonymous. Certain emotions "disturb it" in that some cause it to beat more rapidly, and some slow it and enfeeble it.

Now physiologists have discovered two distinct sets of nerves which influence the heart-rate; the one set on being stimulated makes the heart faster and stronger (accelerator and

augmentor nerves), the other set on being stimulated makes the heart beat more slowly or may stop it altogether (inhibitory nerves). Evidently the former set arouses the heart to greater activity, the latter set induces in it less activity than normal.

The rhythmicality of the heart is not conferred on it by the action of nerves or by the presence of blood or the temperature of the blood, or by any other "external" condition: its rhythmicality is inherent in it, is spontaneous (autogenic). The rhythm of the heart is of the essence of its life: the microscopic cells of the embryo heart beat with a rhythm as soon as they are perceptible at all, and long before nerves have reached them or any blood has been formed.

Spontaneous rhythmicality is the great mystery of life, the central puzzle in biology: if we knew what rhythm really was, understood it "all in all," we should "know what God and man is." The heart is not the only rhythmic portion of the circulatory system. In all animals, portions of the large veins have the power of rhythmic contraction—in the bat sixteen times per minute—and in some animals (frogs, for instance) there are pulsatile sacs or lymph-hearts, dilatations of the lymphatic vessels beating visibly under the skin of the back.

Many other organs exhibit rhythms. The activity of the stomach is rhythmic, also that of the intestines; over which waves of contraction pass at short intervals, the activities also of the gall-bladder, the urinary bladder, and the uterus are all rhythmic.

An interesting thing about rhythmic organs is their inability to have the rate of their rhythm forced beyond a certain limit. No amount of stimulation of the accelerator nerves can increase the rate of the heart-beat beyond a certain limit. Similarly, heating the heart will raise the rate of the rhythm, but only up to a particular figure which can not be exceeded. Working with the pigeon, the author found that the greatest number of beats per minute which the heart (auricle) could give was 300, or five a second; and beyond that it was not possible to force it. Not only, then, is rhythmicality inherent in the living substance of the heart (cardiomyoplasm), but also a power of resisting all influences to accelerate it beyond a certain limit, a kind of "functional inertia," as the author has called it.

Let us now take another example of rhythmic activity as seen in the cilium. A cilium is a minute, whip-like process of living protoplasm projecting from the surface of the cell. There are millions of these cilia covering the mucous membrane of nose, throat and bronchial tubes, where they are for the purpose of lashing mucus, dust and germs towards the nostrils and mouth, respectively. Now, these cilia lash backwards and for-

wards at a characteristic rate of ten to twelve times in the second. Just as the heart makes 72 systoles and 72 diastoles in a minute, so the cilium bends forwards ten times and backwards ten times in a second, or six hundred times a minute, about eight times as fast as the heart. Otherwise put, the period of ciliary oscillation is one tenth of a second instead of eight tenths.

But the rhythmicality of the cilium is as inherent as that of the heart. The cilia receive no nerves, therefore not being innervated they can not possess any rhythm conferred on them from outside by nerves (neurogenic). The cilia are, however, easily influenced in their rate of vibration by changes of temperature and by drugs and poisons. By warming the cilia they lash faster and faster until they attain a speed of about twenty a second, beyond which they can not go; one more example of a limit set. Conversely, cold and narcotics like chloroform slow and finally stop the action just as they do in the case of the heart.

Let us now enquire into the rhythms exhibited by muscles and nerves; almost everybody knows that muscles act (contract or shorten) by having nerve-impulses sent into them either by the will or in an involuntary manner. Soldiers who were wounded in the late war soon came to be aware that if one of their great nerves was cut, they had no longer any power to move certain muscles which they learned to call "paralyzed." Now, these nerves all come from the central nervous system, so that the impulses they transmit must also have their origin in that system. The nerve cells which give rise to these nerves and nerve-impulses are called nerve-centers, and it is these centers which emit impulses to the muscles in a definite rhythm.

Let us take the case of breathing. Normally, an adult breathes about sixteen to eighteen times a minute, that is to say, in a wholly unconscious fashion his diaphragm—the great, curved muscle between the chest and the abdomen—descends eighteen times and rises eighteen times in the minute. There is, therefore, a respiratory rhythm just as there is a cardiac and a ciliary. Now, the diaphragm would not make any descents were it not that it was receiving nerve-impulses through its nerves (phrenics). After these nerves have been cut, the diaphragm is absolutely still. Clearly, then, the rhythm of the activity of the diaphragm is not inherent, but, on the contrary, is conferred by nerves or is neurogenic. The rhythm of 18 to 20 a second must be the rhythm of discharge of nerve impulses from the nerve cells or centers from which the phrenic nerves come. It is the nerve cells that have this rhythm, not the nerves as conductors and not the diaphragm as a muscle.

The actual cells from which the phrenic nerves proceed are, however, not the breathing center, which, situated further up in the central nervous system, constrains the phrenic centers to issue their periodic discharges of nerve-impulses. It is the chief respiratory center, therefore, that has the real respiratory rhythm, which, like the heart's, varies with age and other circumstances. We know very well that the rate of breathing can be profoundly altered by emotional states; some conditions, states of excitement, greatly increase the rate, others slow it or stop it for a time, as in the phrase, "it fairly took my breath away."

Experiments have shown that heated blood accelerates the breathing and cold slows it, and there are drugs which have analogous actions. Further, the will can, for a time, abolish the rhythm altogether. Divers are able intentionally to "hold their breath"; on the other hand the will, if we so wish it, can hurry up the rhythm beyond the rate of the normal. This faculty of having a rhythm which can be altered by the will is quite a rare one amongst the centers of the nervous system.

The normal respiratory rhythm is, then, an additional example of a rhythm inherent in something—in this case in the cells of a nerve center—but capable of responding to outside influences. And again, there are limits set, for neither by the will, nor by emotion, nor by heated blood, nor by drugs, can the rate of the breathing center be forced beyond a certain maximum value.

Breathing is to all intents and purposes an involuntary, unconscious activity: the diaphragm rises and falls throughout life whether we wake or whether we sleep with a regularity that is as constant and with efforts that are as untiring as those of the heart itself. In a word, the rhythm of breathing is not voluntary, although we can interfere with it voluntarily.

But, of course, the nervous system can give us plenty of examples of rhythms of voluntary origin. Take the very simple case of tapping one's finger on the table or on an electric key. I can tap my forefinger once a second, twice a second, three times a second, and so on, until I am tapping it so fast I can barely count it. When this rate is reached, an instrument of simple construction can prove that the finger is being flexed and extended at about ten to twelve times a second. We may note in passing that this is exactly the same as the ciliary rate. Now the instrument will show that beyond ten to twelve a second the ordinary person can not go, although it is possible to train musical technicians to "trill" at a considerably greater rate than that of ordinary people. Still even for experts a limit

is soon reached. The rhythm of the cells of the centers giving rise to the nerves to the fingers is evidently of this sort that whereas the cells can be made by the will to assume any slow rhythm from one to twelve a second, they can not be forced beyond that limit.

What, then, is the rate of inherent rhythm of these centers? Probably ten to twelve a second; although all physiologists are not agreed on this figure, and the point is one not suitable for discussion in the present essay. It is reasonable to suppose that these cells have a normal, natural, inherent rate of discharge which may be one and the same as their maximal rate. Neither by the will nor by artificial stimulation can this maximum be exceeded, not even when the rhythm of the artificial stimulation is much higher than twelve a second. The nerve cells have physiological inertia towards rates of stimulation greater than that of their own maximal rhythm. The respiratory center, on the contrary, we saw, had a normal rate which was *not* also its maximal.

Rhythm or intermittency pervades the nervous system. It has been ascertained that we can not utter syllables (articulate) at a greater rate than ten to twelve a second. What we may call the articulation center has its upper limit set at that figure which we have so frequently met with. The numerical identity of the rhythms of cilium, musculomotor nerve-center, and articulation center can not be accidental.

The periodicities of insects' muscles are of the following orders: The wings of the dragon-fly vibrate at 28 a second, those of the wasp at 110, of the bee at 190, and of the house-fly at 330 per second. The late Professor Mosso asserted that the pitch of the note of a bee setting out on its day's rounds was perceptibly higher than that of the note heard at the close of the day.

It is probable that the receiving or sensory portions of the brain are constructed in such a manner that they, too, have limits in dealing with rhythmic or intermittent presentations.

The spokes of a slowly rotating bicycle wheel can be perceived as separate bright lines, but when the wheel is revolving rapidly the individual spokes fuse into one bright metallic surface, just as the separate slats of a paling viewed from an express train fuse into one continuous surface. The grooves of the milling on the edge of a metal disk spun rapidly under the finger are perceived as constituting a rough but continuous surface. The fusion of the members of a series of instantaneous photographs of moving objects presented in very rapid succession to the eye, as in the kinematograph, is due to this incapacity

of the brain to resolve as distinct in consciousness the separate components of the physical series. If the interval between the successive impressions is longer than about 1/40th–1/50th of a second we do not get fusion, but the well-known and disagreeable state of "flicker." These and many other cases prove that there are strict limits to the perception of rhythms by our brains.

The causes of vital rhythms and periodicities are virtually unknown. Physiologists can describe vital rhythmic actions in their own precise language, but that is all. To say that the cardiac cycle is constituted by the two alternating and opposite phases of katabolic systole and anabolic diastole does not bring us any nearer an understanding of the cardiac rhythm. Protoplasm in general tends to act intermittently. Just as a single tap given to a jelly or to a spring will make these oscillate or vibrate for some considerable time thereafter, so a single or continued stimulus given to living matter will cause it to discharge energy in a vibratory or oscillatory manner.

Nor do we comprehend any better the significance of the particular time-duration of the interval between the recurring events which are being studied. Why, for instance, should the heart beat 72 times a minute and not 7 or 700? Why should we breathe 18 times and not 8 or 80 times a minute? Why should the cilium bend 10 times a second as its normal rate and just twice as fast, but no more than that, when urged to do its utmost? These things are mysteries. The rhythms of functional activity in the female reproductive organs are familiar facts of physiology, but what induces the rhythm and why the periodicity should be as it is are problems at present entirely unsolved.

Probably the necessity of rest to prevent fatigue or exhaustion is one of the purposes of vital rhythms. The heart, for instance, can continue to beat so indefatigably just because the duration of its time of rest (diastole) in the cycle is longer than that of its activity (systole). We sleep by night in order to be active by day. All work and no rest is a physiological outrage: rhythm is an expression of that physiological normality in which work alternating with rest is most economically performed.

It is the most familiar things in life that stand most in need of explanation. Rhythmic action is very familiar, but great is the mystery of rhythmicality. That the heart should exhibit its livingness by phasic activity, that the periodicity of these phases should be controlled by nerves and influenced by certain environmental conditions, are the very A, B, C of physiology, but they are also the alpha and the omega of physiological problems.

THE PROGRESS OF SCIENCE

THE CRITICAL SITUATION OF EDUCATION AND SCIENCE

THE present year is a critical point in the development of science. The present fluid state of research may congeal into static frigidity or it may develop energy to transform the world. The events of the last years—to draw on biological as well as physical science for a metaphor—may have resulted in leaving as their offspring infertile hybrids or in a cross-fertilization leading to unexampled productivity. To complete the circle of the sciences, it may be urged that the result depends primarily not on the existing environment or in the inherited organisms, but on the reactions of the latter to the former, and thus on conditions which are to a certain extent under our own control.

The continental nations of Europe must for a generation devote their energies largely to the repair of destruction, and this holds to a certain extent for England. We have suffered serious losses of men and of wealth, but have only drawn upon an available surplus. We are thus free, as most other nations are not, to control our future. Some two billion dollars a year, for example, will accrue from enforced savings through the suppression of the sale of alcohol. This money can be consumed on luxuries for the rich, it can add three per cent. to the comforts of the great mass of the people or it can be used for investments, the most productive of which are education and scientific research.

There has probably never been a period or a nation in which education and science were more highly regarded than at the present time in the United States. It is generally understood that the aggression of Germany in the war was so formidable on account of the development of its industrial civilization based on the applications of science and the thorough training of the people. Russia was helpless before such an enemy; England and France could reply with somewhat similar weapons, but it required the United States to turn the balance. Equally in time of peace, national prosperity depends on science and education. An autocracy, such as formerly existed in Germany, may realize this fact more promptly and apply its knowledge more effectively in practise than a democracy which leaves higher education and scientific research to private initiative or unorganized public support. It is our business to see that the conditions become equally favorable in our social and political system.

At a time when it is important for us to assume leadership in education and research and the people of the country realize the fact, it is most unfortunate that what may be regarded as an economic accident, has intervened to cause serious difficulty. The depreciation in the purchasing power of money is working serious injustice to many individuals, but in no other case has it done such harm to society as in reducing to nearly half the salaries paid to teachers and to scientific men. They may submit to suffer as a part of the cost of war, but the injury to the nation must be remedied. It is consequently a satisfaction to note that action has recently been taken by the scientific and professional men in the service of the government and by the National Education Association to make known the situ-

ation. We give extracts from the reports of the two groups.

THE CONDITIONS IN THE GOVERNMENT SERVICE

The committee representing the scientific, technical and professional services report that existing conditions in the federal government service disclose the fact that adequate standards of personnel and of performance are not being maintained, that the situation is becoming worse instead of better, that a force which was depleted by the demands of war has become still further depleted since the cessation of hostilities and that this depletion is proceeding at a constantly increasing rate, until it is only a matter of months before it will be humanly impossible for the experienced personnel remaining to perform adequately the duties devolving upon them. While a certain percentage of turnover in an organization is not harmful and may even be desirable, an annual turnover of 25, 50 or even 100 per cent. and more which is occurring at the present time in the federal government service is disruptive of the organizations, reduces the efficiency of the work and largely increases its cost. It is sufficient here merely to cite examples.

Since July 1, 1918, the Forest Service has lost over 700 employees, or 28 per cent. of its total force, including 460 of its technical personnel. The Coast and Geodetic Survey in the same period lost 33 per cent. of its technical force. The Bureau of Standards lost 16.3 per cent. of its permanent staff in the District of Columbia in 1915–16, 27 per cent. in 1916–17, 48.6 per cent. in 1917–18, and 50.1 per cent. in 1918–19, a total of 840 resignations in four years out of an average force of 535. The separations from the combined technical staffs in Washington and Pittsburgh aggregated 1,400 in the four years, out of an average personnel of 473, making an average annual turnover of 85 per cent. with a maximum in the fiscal year 1918–19 of 145 per cent.

These services require men of specialized training and years of experience in the work to be performed before they reach their full efficiency. It is self-evident that the technical work of the government can not be efficiently or economically performed under such circumstances. It would not be done even if the replacements were by individuals of equal ability, but it is not possible to maintain previous standards in such replacements. Individuals of equal ability will not accept the positions offered, and there must be in consequence a constant reduction of standards in order to fill the vacancies. Not only does the excessive turnover result in reduced amount of work for the same number of employees, and in reduced quality, but it also results in increased cost per unit of work performed. Studies made by the Coast and Geodetic Survey, in relation to its commissioned personnel, show that the aggregate cost during the fiscal year ending July 1, 1920, of using experienced men for training new employees, of lost time due to personnel changes, and of lessened efficiency due to inexperience is likely to be more than 25 per cent. in excess of the total annual payroll for such personnel.

The most serious aspect of the situation is in the fact that the demand from the outside is for the highest grade men, for the trained professional workers and for the best of the administrative officers—individuals difficult to replace in any circumstances, and particularly difficult to replace under present conditions. Many of the most efficient and most valuable employees are leaving; the less efficient and less

valuable remain. The net result is a constant deterioration in personnel which, if continued, will eventually result in reducing the government service to a mere training school for private business.

THE SALARIES OF EXPERTS IN THE FEDERAL SERVICE

The committee has segregated 4,332 positions into the various ranks, showing for each rank the number of positions, the mean of the salaries paid in 1919 and 1915, and the percentage of increases in the mean from 1915 to 1919. A temporary bonus of $240 per annum for salaries of $2,500 and under is now in effect. This bonus is applicable to practically all positions in the three lowest ranks, to probably about 75 per cent. of the positions in the fourth rank, to about 10 per cent. of those in the third rank and to none in the second and first ranks. If bonuses are added on these assumptions to the present average base salaries, the total percentage increases in the several ranks since 1915 would be approximately as follows:

TABLE II

Rank	Title	No.	Salary	Increase
1	Senior	51	$5,170	3.3%
2	Full	184	3,275	5.0
3	Associate	408	2,724	8.9
4	Assistant	1037	2,296	17.2
5	Junior	1368	1,872	26.2
6	Aid	1050	1,488	32.2
7	Junior Aid	234	1,152	45.7

The committee states that even if it could be assumed that 1915 salaries were sufficient for maintaining an adequate personnel, it is apparent that the increases since that date have lamentably failed to keep pace with the reducing value of the dollar in which they are paid. Salaries paid in the lower ranks in 1915 were approximately equal to salaries paid for similar positions in private employment. The disparity between government salaries and those paid in private business increased, however, for each step up in the rank of positions occupied. Amounts paid in the full professional, associate and senior ranks were far below the amounts paid for similar employment and responsibilities in private business, with the result that even in 1915 it was difficult to secure and retain an adequate personnel for the higher positions. Nevertheless, in such adjustments as have been made since 1915, these three upper ranks have been practically ignored. It is not surprising that under such circumstances so large a proportion of men in these grades are leaving the government service.

If the flood of resignations from government service is to be stopped and if the service is to be maintained on a standard commensurate with the importance of the work to be performed, there must be a radical readjustment in the present salary scale for the technical, scientific and professional services—a readjustment which will recognize the commercial value of the service performed and realize the fatal blunder of attempting to do the business of the government on a compensation basis which private business abandoned years ago.

After investigation, the advisory committees of the technical, scientific and professional services submit a scale as representing, in their judgment, the lowest amounts under which it will be practicable to recruit and retain in the government service a properly qualified personnel in any class of its technical, professional or scientific work. In support of this scale comparisons are made with rates of pay of skilled and unskilled labor, and certain technical positions under the "Macy Scale," and the salaries received by several hundred government employees who have left the service.

TEACHING POSITIONS IN THE UNITED STATES

THE secretary of the National Education Association reports that more than 100,000 teaching positions in the public schools of the United States are either vacant or filled by teachers below standard, and the attendance at normal schools and teacher-training schools has decreased 20 per cent. in the last three years.

Letters were sent out by the association in September to every county and district superintendent in the United States asking for certain definite information. Signed statements were sent in by more than 1,700 superintendents, from every state, representing 238,173 teaching positions. These report an actual shortage of 14,681 teachers, or slightly more than 6 per cent. of the teaching positions represented, and 23,006 teachers below standard who have been accepted to fill vacancies, or slightly less than 10 per cent. It is estimated that there are 650,000 teaching positions in the public schools of the United States, and if these figures hold good for the entire country there are 39,000 vacancies and 65,000 teachers below standard.

These same superintendents report that 52,798 teachers dropped out during the past year, a loss of over 22 per cent. On this basis the total number for the entire country would be 143,000. The reports show that the shortage of teachers and the number of teachers below standard are greatest in the rural districts where salaries are lowest and teaching conditions least attractive.

The states in which salaries and standards are highest have the most nearly adequate supply of teachers. California shows a combined shortage and below standard of 3½ per cent.; Massachusetts shows 4½ per cent., and Illinois 7 per cent. In at least six of the southern states more than one third of their schools are reported either without teachers or being taught by teachers below their standards. Nearly all of the superintendents declare that teachers' salaries have not increased in proportion to the increased cost of living, nor as salaries have increased in other vocations, and that teachers are continuing to leave the profession for other work.

Reports received by the National Education Association from normal school presidents show that the attendance in these teacher-training institutions has fallen off alarmingly. The total attendance in 78 normal schools and teacher-training schools located in 35 different states for the year 1916, was 33,051. In 1919 the attendance in these same schools had fallen to 26,134. The total number of graduates in these schools in 1916 was 10,295, and in 1919, 8,274. The total number in the graduating classes of 1920 in these 78 schools is 7,119. These figures show a decrease of over 30 per cent. in four years in the finished product of these schools.

SCIENTIFIC ITEMS

WE record with regret the death of Dr. Elmer Ernest Southard, professor of neuropathology in Harvard university; of Dr. Christian R. Holmes, dean of the college of medicine, University of Cincinnati; of Rear Admiral John Elliott Pillsbury, U. S. N., retired, president of the National Geographical Society.

DR. BURTON E. LIVINGSTON has been elected permanent secretary of the American Association for the Advancement of Science, to succeed Dr. L. O. Howard, elected president of the association. Dr. Livingston will retain the professorship of plant physiology at the Johns Hopkins University, and the office of the association will remain at the Smithsonian Institution.